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THE SYSTEMS APPROACH TO WAREHOUSE PLANNING AND DESIGN

A THESIS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Physical Distribution

"Physical distribution can be broadly defined as that area of business management responsible for the movements of raw materials and finished products and the development of movement systems." (1) There are a number of activities which must be performed to carry out the physical distribution function efficiently. Some of the major ones are:

1. Marketing
2. Transportation
3. Materials Handling
4. Warehousing
5. Packing and Packaging
6. Inventory Control
7. Communications
8. Data Processing

It is usually the responsibility of the top management of a company to combine these divergent activities under proper authority to operate them efficiently at minimum cost.

Recently, emphasis in physical distribution has developed for several reasons. First of all, methods improvements increasing worker efficiency have balanced or neutralized the increase in manufacturing costs, so that rising distribution costs now result in a greater proportion of total costs. A survey conducted by Distribution Age shows that in six major industry groups physical distribution costs, expressed as a percentage of manufacturers' selling price, ranged from 10% to 30%. Furthermore, an analysis of the distribution portion of the retail price of a typical consumer product shows that the total cost added by several functions break down as follows (2):

Table 1. Significance of Distribution Costs

FUNCTIONS	TOTAL COST ADDED	
	actual	per cent
Materials..................	$ .23	11.5%
Manufacture................	.14	7.0
Selling....................	.81	40.5
Distribution...............	.82	41.0

For a typical case, cost added by distribution was higher than that of any other element. This means that in today's complex business world, if a firm wants to remain competitive, it must be on the lookout for potential economies. One of the easiest places to look for such opportunities is in the distribution cost.

Changing patterns of distribution have resulted from several social, economic, and technical pressures. These trends are complex and their effects are interrelated, but some have had great effects on physical distribution activities. Among them are (3):

1. Consumer demand for product variation has caused product sizes, styles, capacities, and features to multiply.

2. New products have increased in number, thereby creating new demands and affecting older products.

3. Retail outlets have been reduced in number, but have grown bigger in size.

4. Changes have resulted in inventory policies due to increasing costs.

5. The intensity of competition has led to demand for better customer service.

Technological progress has made possible the integration of the entire distribution function. Communication networks and data processing equipment have provided the speed to do so. Also problems which were considered unsolvable due to the great amount of data necessary to obtain a solution, are now being quantified by the computer. Plant and warehouse location problems, inventory level problems, scheduling problems, and many other distribution problems can now be simulated, mathematically formulated and solved. Operations Research techniques such as linear programming, queueing theory, game theory, and dynamic programming are gaining acceptance as methods of obtaining more accurate solutions than were previously possible.

Tremendous improvements have been made in transportation and handling systems which have shortened delivery times and so affected stock location and stock levels. The use of the jet airplane to move cargo has cut the delivery time between almost any points in the world to a matter of hours. Unitization of cargo loads has reduced the handling of materials and also provides (4):

1. better product protection,
2. faster processing and shipping,
3. simpler inventory taking,
4. lower transportation rates,
5. shorter transport time, and
6. no split-lot delivery problems.

Finally, there are a number of qualitative or intangible factors which can affect physical distribution. Some of these would vary from company to company depending upon the goals of the firm. They will depend upon particular situations but should not be overlooked when planning an efficient distribution system. Some more common intangible factors are:

1. Customer service
    A. product quality
    B. promptness of deliveries
2. Competitive pressures
    A. competitor's reactions
    B. competitor's capabilities
3. Type of market
    A. oligopoly
    B. perfect competition
    C. monopolistic competition
4. Trends in industry
    A. centralization
    B. decentralization
5. Labor relations
    A. less fatigue
    B. stable employment

While a large number of papers have been written and much work has been done in some areas of physical distribution, others have been somewhat overlooked. One of these areas is warehousing, which represents a major and vital segment of the distribution system. The function of warehousing is to add "time" and "place" value to items by having them available when and where requested.

Apple (5) defines warehousing as:

> a function which determines what and how much goods to store; provides the proper space for their safekeeping; controls the total storage activity; and provides a system to economically coordinate the necessary activities, facilities and manpower.

Objective

This thesis will attempt to analyze the many factors involved in the design phase of warehousing using the total systems approach to this segment of the physical distribution system. Each step of the design phase will be carefully analyzed to determine the critical factors governing the design.

The primary purpose is to develop a chronological sequence of steps, representing phases of the design, which can serve as a guide to the management of a company. This will help then to evaluate the decisions required to determine whether or not to include a warehouse within the distribution system. If a warehouse is desired the procedure will suggest how to proceed with the design.

CHAPTER II

ECONOMIC JUSTIFICATION OF WAREHOUSES

Consumer Behavior

One of the major problems existing within the production-distribution system is that of matching the demand with the supply for goods. While producers want to keep production rates as uniform as possible consumption expenditures possess so many random variables that their interactions are almost impossible to predict.

Economic studies of consumer behavior at micro-economic levels have devised several theories, none of them completely satisfactory, which have attempted to predict consumer behavior.

The first theory stems from the revolutionary work of J. M. Keynes (6). The theory proposes that aggregate consumption is a function of aggregate disposable income. However, forecasts of post World-War II consumption were quite off the mark because other important factors which affect consumer behavior were not taken into account.

Since then several attempts have been made to develop more sophisticated models which can predict consumer behavior. Duesenberry (7), after an extensive study, concluded that differences in consumption behavior could be explained by differences in the level of relative income. This, however, was not the only explanation since other studies have shown that factors such as security, wealth, new products and time point toward the same conclusion. Friedman (8), argues that the relevant variable explaining the consumption of an individual is his permanent income, by which he means the present value of his expected future receipts. Watts (9), proposes that the relevant variable that explains the level of consumption spending is expected income. He finds age, education, occupation, race, and location to have significant effects on the expected income.

It can therefore be seen that wide variations exist between theories attempting to describe consumer behavior. It is also a known fact that no theory has been accepted among economists because each one has its pros and cons. However, the failure to include in the models factors known to be important determinants of consumer behavior due to the complex interrelationship involved will maintain the forecasting of consumption expenditure a very difficult task.

Since the customer demand for products is so random and unpredictable it is almost impossible to expect producers to match it. Therefore, warehouses exist within the production-distribution system to permit producers to operate at a uniform rate. These warehouses act as "absorbers" of the differences between demand and supply for products. Whenever demand exceeds supply the result is an outflow of material from the warehouse and a reduction of inventories. If supply exceeds demand, then the opposite occurs. If the differences between demand and supply are too large, then this outflow or inflow of material from or into the warehouse serves as a signal to the producers that production rates need to be adjusted.

Feasibility of a Warehouse Component

The decision to include a warehouse component in the production-distribution system (see Figure 1) of a firm creates problems of two types:

1. problems related to the establishment or design of the warehouse, and

2. problems related to the operational efficiency of the unit.

Problems of the first type refer to the series of decisions, made by the management of the firm, which are the inputs upon which the warehouse will be developed as an operational unit. Once the warehouse is operational, management faces the continuing problems of efficiency and control of the operations.

However, before the decision to include a warehouse

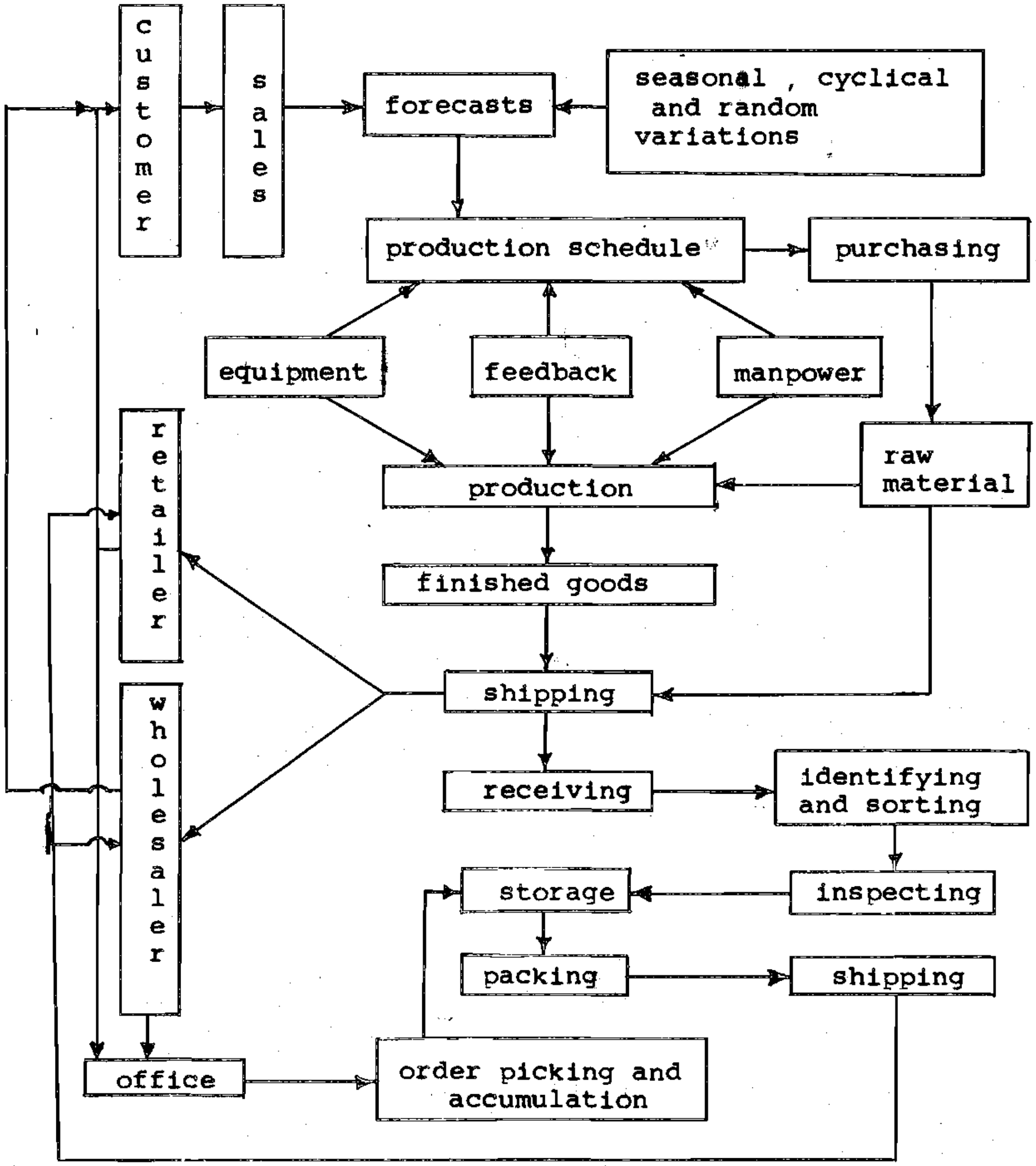

Figure 1. Production-Distribution System

in the distribution system is reached a careful evaluation of the feasibility of such a component must be carefully made. The final decision depends upon the distribution effectiveness attainable by the system, which is judged by the standards of minimum cost and maximum service.

The first step in the feasibility study of the warehouse component is an economic study of the alternative distribution channels available. A channel of distribution can be defined as the path through which a product flows from the manufacturer to the consumer (see Figure 2). The selection of a distribution channel is a very complex task depending upon many factors such as (10):

1. Demand of product (s)
2. Demand variations
3. Population
4. Personal income
5. Value of product (s)
6. Inventory levels
7. Seasonality of production
8. Perishability of product (s)
9. Product line
10. Dynamic factors

No attempt will be made here to solve the problem of the selection of a distribution channel since it is beyond the scope of this study. However, it is important to know the alternatives available and the factors influencing their selection.

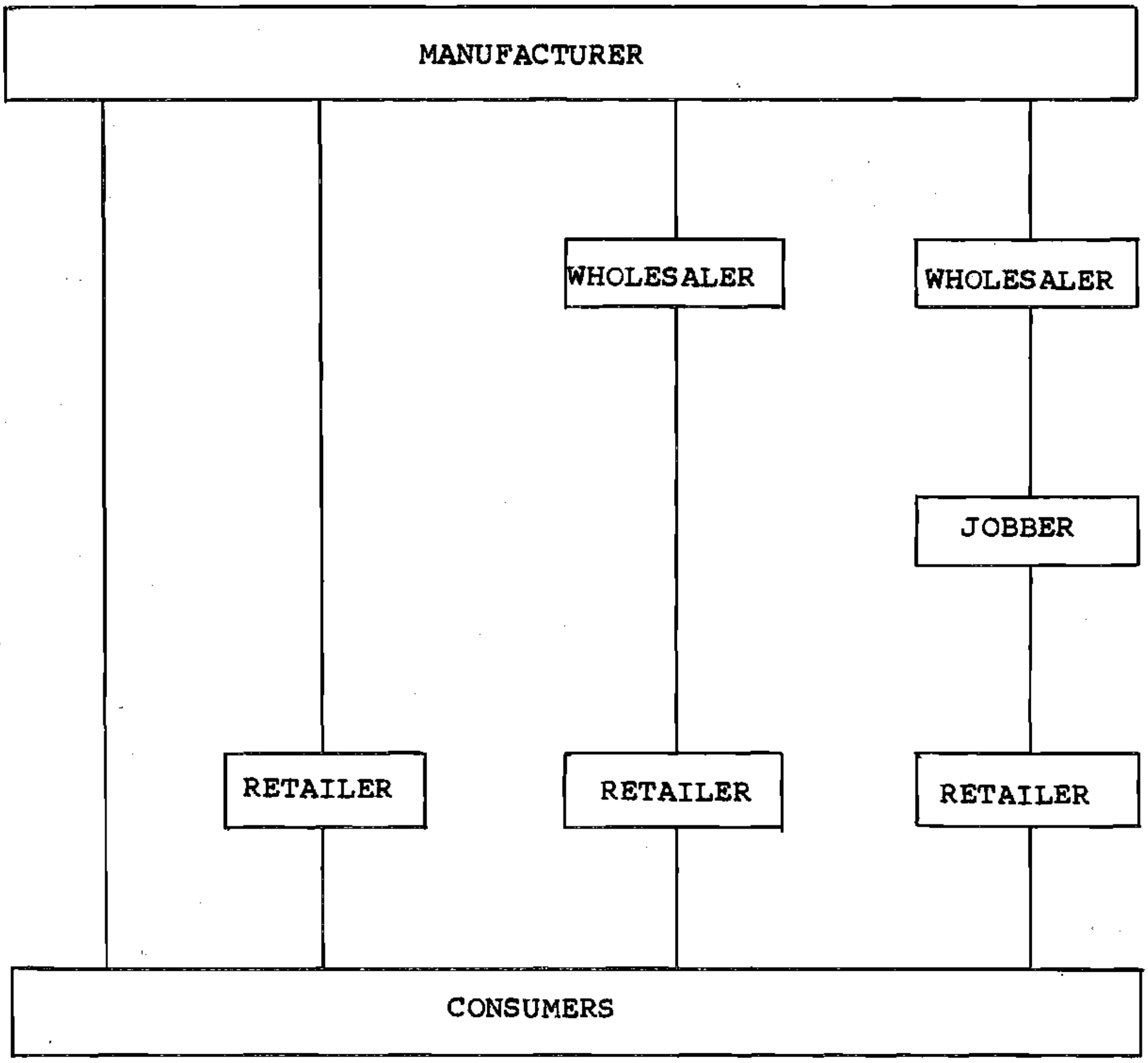

Figure 2. Simplified Alternative Distribution Channels (11)

Economies gained by including a warehouse in a distribution system are mainly in the form of lower transportation rates achieved through consolidation or "pooling" of shipments as opposed to other forms of direct shipment from plants. But the construction, maintenance, and operation of a warehouse costs money. These costs can be classified as (12):

FIXED	VARIABLE
1. Depreciation	1. Maintenance
2. Taxes	2. Utilities
3. Insurance	3. Labor
4. Rents	4. Loss and damage
5. Supervision personnel	5. Materials (packing)
6. Clerical work	6. ~~Postage~~
7. Interests on investment	7. Office supplies
	8. Communications
	9. Equipment rental
	10. Miscelaneous

If there exists a critical volume or break-even point beyond which freight savings exceed the warehousing costs then the construction of a warehouse may be justified. This is shown in Figure 3, where hypothetical warehousing costs are compared with other distribution alternatives.

Letting:

VC_n = Variable cost associated with the n^{th} distribution alternative.

FC_n = Fixed cost of n^{th} distribution alternative.

TC_n = Total cost of n^{th} distribution alternative.

Where:

$$TC_n = FC_n + VC_n$$

and,

X = Tons of material distributed.

Alternative #3 is a warehouse distribution system.

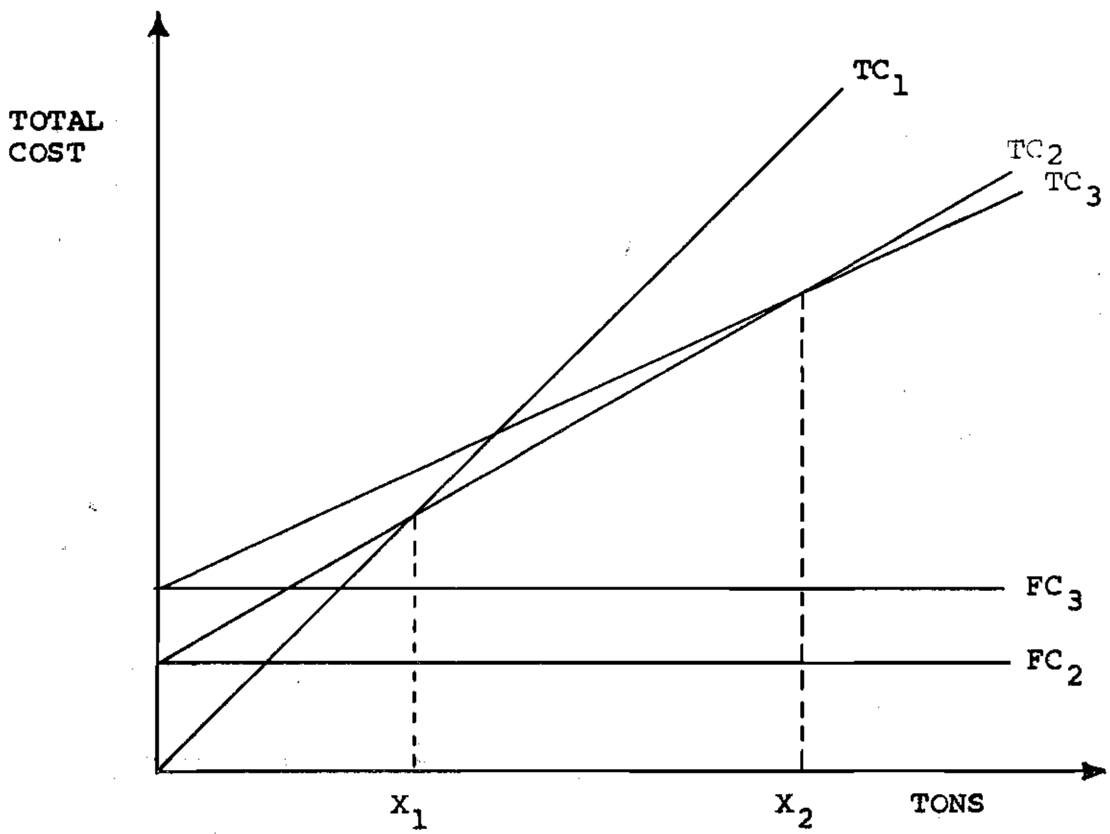

Figure 3. Break-Even Analysis of Distribution Costs

Simultaneous consideration of three distribution alternatives reveal that for small shipments (up to X_1), alternative No. 1 gives the lowest total distribution costs. However, as the volume of material moved increases (range between X_1 and X_2), alternative No. 2 results in lowest total cost due to the smaller slope of the variable portion of the cost curve. To the right of point X_2 is where a warehouse operation becomes the more economical alternative. The greater the volume achieved to the right of X_2, the greater the potential savings from warehouse operations. If this total cost method of analysis is considered, jointly or separately, for all the possible alternatives, then the volume or range, if it exists, over which warehousing operations are economically justified can be found by the use of graphic and/or algebraic techniques.

Using the previous example, the critical volume X_c can be found as follows:

Let

a = Slope of warehousing alternative TC curve.

b = Slope of TC_2 curve.

The break-even point is where

$$TC_2 = TC_3$$

$$FC_2 + VC_2 = FC_3 + VC_3$$

$$FC_2 + bX = FC_3 + aX$$

$$X_c = \frac{FC_3 - FC_2}{b - a}$$

This critical volume will be the deciding factor in determining the feasibility of the warehouse component.

The Warehousing Problem

A mathematical model has been developed by Hanssmann (13), for warehouse operations, which permits decision variables such as inventory levels and material received or shipped to be manipulated, in order that a profit objective function be optimized. The warehouse receives or buys the quantity X_i at unit cost C_i and sells the quantity Y_i at unit price P_i. Both the input and the output in period i are under control; but, the unit costs and prices for all periods are not.

Assuming that:

1. A quantity bought in a given period cannot be sold in the same period.
2. A = initial inventory.
3. B = warehouse capacity.
4. C_i= cost per unit.
5. P_i= selling price per unit.
6. X_i= amount bought.
7. Y_i= amount sold.

The problem is to determine the quantities X_i and Y_i so as to maximize the over all profit.

$$P = \sum_{i=1}^{n} (P_i Y_i - C_i X_i)$$

subject to the following restrictions:

Buying constraints

$$A + \sum_{j=1}^{i} (X_j - Y_j) \leq B$$

Selling constraints

$$Y_i \leq A + \sum_{j=1}^{i-1} (X_j - Y_j)$$

Nonnegativity constraints

$$X_i, Y_i \geq 0 \quad (i = 1, \ldots., n)$$

The maximum profit will be a function of the original quantity of stock, A, and the duration of the process. Solutions to the problem can be obtained by either linear or dynamic programming.

This type of programming works only after the warehouse unit is completely operational. It can help to control the operational efficiency of the unit, but it cannot be used at the design stage.

CHAPTER III

WAREHOUSE LOCATION

Problem Characteristics

The warehouse location problem involves the determination of the number and sizes of service centers to supply the demands of the service area. The general problem may be stated as follows (14):

Given:

1. The location of each destination.
2. The requirements at each destination.
3. A set of transportation costs for the region of interest.

To determine:

1. The number of sources.
2. The location of each source.
3. The capacity of each source.

The objective is to determine which demand centers are supplied by which warehouses so that total distribution costs are minimized. This distribution cost consists of the transportation cost plus the cost of building and operating warehouses.

This problem seems to be influenced by many factors, but it appears that marketing forces, transportation costs, and warehouse operating costs are the most important.

Distribution systems must be designed so as to compliment all stages of the marketing process in order to realize an efficient total marketing effort. Therefore, it is of utmost importance that such an important link in the distribution channel be located so that maximum economies and efficient flow of materials are obtained

Transportation costs are determined by the relationship existing between purchasing points, quantities of material shipped, the different transportation means available, product characteristics such as weight and volume, and the distances involved. By determining sales and purchasing points for alternative locations simple mathematics will reveal which location minimizes total transportation costs.

There are also many intangible factors which may influence warehouse locations. Among the important factors to consider are (15):

1. Availability of labor
2. Labor costs.
3. Labor laws.
4. Convenience to customers and suppliers.
5. Transportation facilities.
6. Favorable tax structure.
7. Center of particular industry.
8. Local cooperation.

9. Availability of buildings or property.

10. Living costs.

11. Utilities.

12. Climate.

General Procedure

The general procedure for the selection of the site for a warehouse, once a set of specification and objectives has been completed to guide the entire process, is as follows (16):

1. Regional evaluation - This consists of a geographic evaluation to determine which areas qualify, according to the management specifications, for further examination. The next step is the selection of the areas which best and more economically achieve the location objectives.

2. Community evaluation - Having several "acceptable" areas already selected from the preliminary territorial analysis, a further analysis must be made of communities within each area which are capable of satisfying location requirements. This includes an evaluation of necessary factors such as utilities, transportation facilities, and especially labor. Total supply of labor, local skills available, wage rates, and characteristics of the labor supply should be ascertained. Further investigation should also include

consideration of intangible factors such as local politics and community attitudes.

3. Site evaluation - At this stage attention must be given to the actual physical requirements, to cost analysis, and to consideration of intangibles. The direct cost of the site is the governing factor, but set up and operating expenses such as road access, rail sidings, and utility hook-ups must be given proper consideration. The expansion plans of the firm should not be forgoten when making the final evaluation for the selection of a site.

4. Site selection - The final selection of a site is the last step of the analysis. The site which most economically satisfies the warehouse requirements can be finally selected.

Warehouse Location Models

There have been several mathematical models developed to help solve the difficult problem of determining profitable geographic locations for the warehouse in the distribution system. Difficulties arise out of the fact that:

1. the set of possible warehouse locations constitutes a two dimensional continuum, and

2. the computational difficulties that arise in a concave-minimization program due to the nonconvexities associated with the costs of building and operating warehouses.

Baumol and Wolfe (17), while investigating the number and location of the warehouses of a large corporation, approached the problem in a simpler way. First of all, a crucial simplification was made possible by the fact that the company rents space in public warehouses, which permits the elimination of the capacity constraints and narrows the choice of locations to those warehouses possessing the required physical characteristics.

The problem can then be mathematically formulated as follows (18):

Let

X_{ijk} = quantity shipped from factory i via warehouse j to retailer k.

$C_{ijk}(X_{ijk})$ = cost of shipment including inventory cost.

Q_i = quantity shipped from plant i.

S_k = quantity required at destination k.

R_j = capacity of warehouse j.

The problem is to minimize the total delivery cost

$$\sum_{ijk} C_{ijk}(X_{ijk}),$$

subject to:

$$\sum_{jk} X_{ijk} = Q_i,$$

$$\sum_{ik} A_{ijk}(X_{ijk}) \leq R_j,$$

$$\sum_{ij} X_{ijk} = S_k$$

where all $X_{ijk} \geq 0$.

This problem resembles the standard transportation problem. There are only three differences: a) the non-linearity of the cost function; b) the warehouse capacity constraint, which can be ignored for the reasons explained above; and c) the need for three subscripts notation arising out of the necessity of routing each flow through a warehouse.

The first difference can be eliminated by assuming a linear objective function, and the three subscript notation is replaced by a two subscript notation by using the rule of making shipments via the warehouse that offers the lowest delivery costs. This reduces the problem to a standard transportation problem, the optimum values of whose variables can be found by the standard method.

Feldman, Lehrer, and Ray (19), used a different approach and developed a heuristic program for solving warehouse location problems when the economies of scale are represented by continuous concave functions.

Mathematically they consider single-product problems of the form (20):

$$\text{Min} \sum_{ij} C_{ij} X_{ij} + \sum F_i(T_i)$$

such that

$$\sum_i X_{ij} = D_j, \text{ and all } X_{ij} \geq 0$$

where

X_{ij} = Flow from warehouse i to demand center j.

$T_i = \sum_j X_{ij}$ = Throughput of warehouse i.

C_{ij} = Unit cost of flow X_{ij}.

D_j = Demand at center j.

F_i = Warehousing cost function for warehouse i.

The work was an extension of Kuehn and Hamburger's (21) work, and consisted of developing heuristics for assigning customers to those warehouses that have been "opened". This assignment was no longer trivial for non-linear F_i as it is in the linear case previously considered. On the whole the results obtained with the heuristic program were most satisfactory. A modification was made in the method used to generate better solutions. It was suggested that dropping rather than adding warehouses was a better way of attacking the problem.

The method by which the program approaches the problem is to first evaluate, for each customer, the total incremental cost, associated with shipments from each of the potential suppliers. Since a reference level for warehouse size is required for cost comparisons, a local customer set (LCS), was defined as consisting of those customers to whom the warehouse is closest on transportation cost basis. The warehouse can then be said to have a local volume that is the sum of the individual demands in the LCS.

Once local volumes have been established, warehouse-customer allocations are independent of those made for all other customers. An examination is made of the incremental cost of supplying a given customer from each of the available warehouses assuming that these warehouses have, throughput levels equal to their local volumes, of the allocation in question.

The "drop" approach consists of starting with all potential warehouse sites being utilized as suppliers and eliminating them one at a time until no further cost reductions are realized. The flow chart of this "drop" approach is shown in Figure 4 (22).

The authors conclude that heuristic techniques can generate near optimal solutions to large scale warehouse location problems having continuous nonconvex warehousing cost functions. However, it was also found that optimal patterns are highly sensitive to the form of the warehousing cost curve. Therefore, oversimplifications during the formulation phase of the problem should be avoided.

Smykay and Fredericks (23), developed a simpler index method for evaluating warehouse locations. It offers managers a simple way to evaluate competitive advantages under changing market conditions when

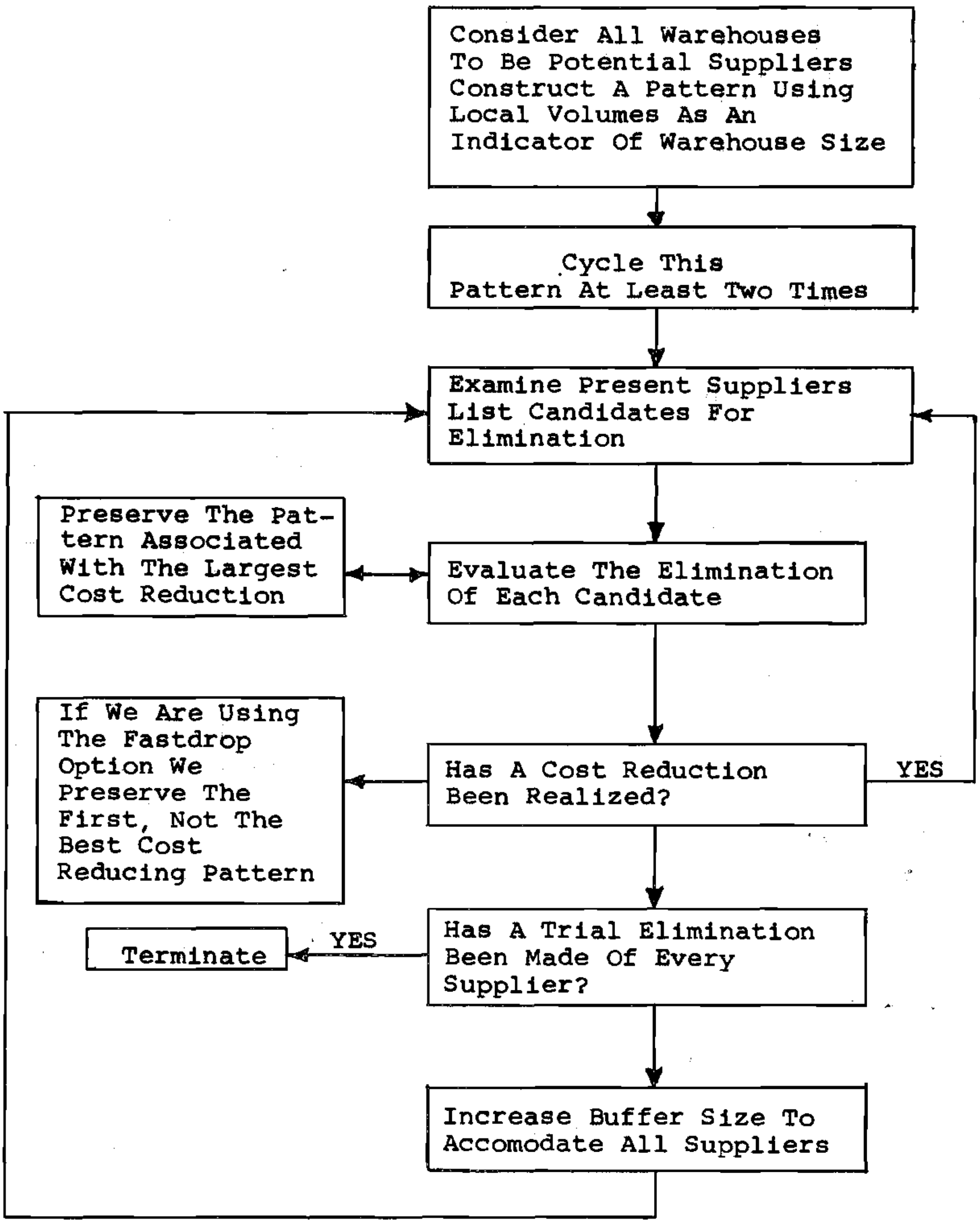

Figure 4. The Drop Approach Flow Chart

transportation costs are of major consideration.

The first step in the evaluation process consists of identifying customers and their volume of demand. A scale map showing the locations of all customers is then constructed using two arbitrary points as references for the entire analysis. Then, the costs of providing service to those customers from the present location are obtained.

"The ton-mile center of a market area is defined as the calculated point where transport ton-miles needed to serve all customer locations are minimized (24)." In many cases warehouse location near the ton-mile center of a geographic area will tend to minimize transportation costs.

The ton-mile center of an area is determined from the following information:

1. Customer identification.
2. Customer location from reference point in miles north and east.
3. Weight transfered to each customer in tons per year.

The procedure calls for a calculation of the "pull" each customer has on the ton-mile center. This is obtained by multiplying both north and east location miles by the number of tons per year. The coordinates of the ton-mile center are then obtained by dividing the weighted northerly and easterly "pulls" by the total weight transfered during the year for all customers. These results are summarized in table 2, where an actual example of ton-mile center calculations is presented.

Table 2. Ton-Mile Center Calculation (25)

Customer	Location miles north	Location miles east	Weight tons per year	Weighted northerly pull	Weighted easterly pull
A	40	65	50	2,000	3,250
B	103	28	200	20,600	5,600
C	85	60	50	4,250	3,000
D	42	84	20	840	1,680
E	70	116	150	10,500	17,400
F	37	125	20	740	2,500
G	40	156	120	4,800	18,720
Totals	-	-	610	43,730	52,150

$$\text{Northerly miles } \frac{43{,}730}{610} = 72 \text{ miles north}$$

$$\text{Easterly miles } \frac{52{,}150}{610} = 86 \text{ miles east}$$

Computation of total mileage from the ton-mile center should be compared to the previous mileage from the present location in the following formula (26):

$$\left(\frac{\text{Present location ton-miles}}{\text{Ton-mile center location ton-miles}}\right) - 1$$

$$= \text{Opportunity for cost reduction}$$

As the left side of the equation approaches 0, opportunities for savings by shifting warehouse location seem improbable. However, as the number approaches or exceeds 1, a careful cost evaluation should be made since possible yearly savings should make a move mandatory.

Errors in Warehouse Location

A three year survey conducted by a leading consulting firm of more than 1,000 manufacturing corporations shows that the 10 most common and costly mistakes in warehouse location are (27):

1. Failure to consider total costs
2. Carelessness in checking site
3. Failure to anticipate growth
4. Underestimating the importance of taxes
5. Miscalculating labor costs
6. Inadequate labor reservoir
7. Lack of distribution knowhow
8. Lack of supporting facilities
9. Location by imitation or compromise
10. Incorrect cost relationship

These results are the frank answers of warehouse managers who were asked the question: "Has your warehouse location been completely successful and, if not, what have been the most important problems?"

The masive shifts of industrial and consumer markets from traditional manufacturing centers coupled with parallel movement of people to new and growing areas represent to management a great problem in physical distribution. Although this dispersion is producing more uniform markets throughout the country, it is also increasing physical distribution costs. Since management is aware of the complex interrelationships existing between the many factors involved in warehouse location, it is no surprise to see that all sections of the country are experiencing a record level of warehouse location activity.

CHAPTER IV

SELECTION OF A MATERIALS HANDLING SYSTEM

General Procedure

The selection of a materials handling system for any industrial facility is a complex problem that requires the consideration of many factors. In the planning process of a distribution warehouse a materials handling system should be selected as early as possible. Since there are no physical limitations there is complete freedom in the selection of a system. Once the handling problem is completely defined the most economical handling system can be determined. However, this is not an easy task since there are a number of systems capable of satisfying the required movements. Therefore, a logical sequence of steps for gathering and analyzing information and a clear understanding of the nature of the movement requirements is necessary before a specific system can be selected.

In general, the procedure for analyzing the selection of a materials handling system is as follows (28):

1. Identify the problem(s)

The first step in analyzing a materials handling problem is to identify the problem. This is essential to permit further analysis to be conducted correctly. In some cases the general problem may be obvious, therefore, not much time should be wasted at this stage and the next step should be carried out immediately.

2. Define the handling task

In order to determine which systems are capable of performing the handling task, a definition of the task should be the second step on the analysis. Then, it is possible to establish the boundaries within which the investigation will proceed.

3. Determine the scope and limitations

Having defined the material handling problem, the next step is to determine its scope and limitations. The total system approach should always be used to make sure important areas or factors are not overlooked. The entire range of the problem must be identified to be able to obtain a solution for its complete framework. Also, certain physical characteristics such as floor loads, ceiling heights, column spacing, and other structural details of a building which may limit the freedom of choice of the handling system, must be considered. In some cases these may even dictate the use of certain systems.

For example, consider the case of a warehouse whose roof structural members have been designed with just sufficient strength to protect it from the weather. The low strength of the members may rule out all the possibilities for any type of overhead conveyor system, and force the use of a floor supported handling system.

4. Collect and analyze data

This step consists of a collection of data on each available system, so that a differentiation and an evaluation of each alternative system is possible. This will permit the determination of satisfactory systems which complete all the necessary requirements. From these data, the characteristics of the satisfactory systems can also be determined.

At the same time that data is being obtained for the handling system, the same must be done for the handling task. This means that factors such as the following must be known for all types of material to be moved.

1. Volumes to be handled
2. Distances of movements
3. Input and output rates
4. Product(s) physical characteristics
5. Frequency of movement
6. Source and destination
7. Route
8. Unit handled
9. Storage environment
10. The mode of transportation
11. Conditions upon arrival
12. Conditions shipped out

These factors will determine the characteristics of each activity area and will constitute the criteria for a final comparison, which will lead to the final selection of a handling system.

5. Identify alternatives available

This phase of the procedure consists of identifying as many of the alternatives methods available for performing the material handling task as possible. Due to the fact that there are so many different kinds of equipment from which to choose, it is impossible to consider all of them in the analysis. Therefore, the more common types of equipment should always be prefered, since the availability of service and repair parts makes their maintenance easier and cheaper. However, the lesser known types of equipment should not be overlooked, since it is possible that the problem(s) at hand can best be solved by one of these.

In general, materials handling systems can be classified according to their functional operation as (29):

A. Haulage Systems

a) Track Dragging Systems
b) Industrial Railroads
c) Industrial Hand Trucks
d) Skid Platforms
e) Powered Industrial Trucks
f) Trackless Trains

B. Elevating Systems

a) Vertical-Type Conveyors
b) Fixed Arm Cranes
c) Fixed Arm Derricks

d) Fixed Hoists
e) Winches
f) Stackers
g) Levelers
h) Elevators

C. Conveying Systems

a) Sliding Friction Conveyors
b) Rolling Friction Conveyors
c) Belt Conveyors
d) Cable Conveyors
e) Chain Conveyors
f) Portable
g) Pneumatic
h) Screw

D. Transferring Systems

a) Monorails
b) Derricks
c) Cranes

E. Self-Loading or Unit Load Systems

a) Skids
b) Skid Jacks
c) Platform Lift Trucks
d) Pallets
e) Fork Trucks

By a material handling system is meant a combination of several methods and/or pieces of equipment that accomplish a handling task. Handling systems are designed, but the pieces of equipment composing it are selected. The above list presents general categories of equipment available under each type of system each of which can be further subdivided into various groups.*

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*For more information, see Apple's Fundamentals of Materials Handling, Chapter VI, p. 6.

6. Identify the factors that differentiate the alternative systems

Having identified the alternatives available for doing the handling task, a list of all the factors that differ among the systems must be made. This means that factors such as:

1. Equipment capacity
2. Flexibility
3. Obsolescence
4. Required accessories or attachments
5. Availability of equipment and repair parts
6. Maintenance
7. Compatibility
8. Adaptability
9. Cost

must be known for all alternative systems.

The advantages and disadvantages of each system characteristics should be pointed out, since the differences among systems will be the deciding factors in determining the efficiency and cost of each system.

An analysis of how differences in product characteristics and movement characteristics can serve as an aid to select materials handling systems for a warehouse will be presented later in the chapter.

7. Classify the factors

An examination of the factors differentiating between the alternative systems will reveal that some factors can be reduced to the common dollar ($) denominator, while others defy quantification. Since the approach to evaluate these factors is completely different, it should be done separately. Therefore, it is wise to classify the factors as tangibles or intangibles.

8. Reduce all tangible factors to a common denominator

Use compound interest formulas to reduce all monetary factors to an equivalent annual cost for each system under consideration.

9. Evaluate intangibles

Since intangible factors cannot be reduced to dollars, some method should be established for their evaluation. This is very subjective and will therefore depend on the judgement of the person making the evaluation. However, this does not justify their ommission from consideration.

10. Make a final decision

Finally, after a conciencious evaluation of tangible factors, intangibles factors, and the relationship existing between them has been made, the system which represents the maximum economy should be selected.

The entire general procedure for selecting a Materials Handling System is summarized in Figure 5.

Material Handling Principles

A set of rules or principles exists which should be

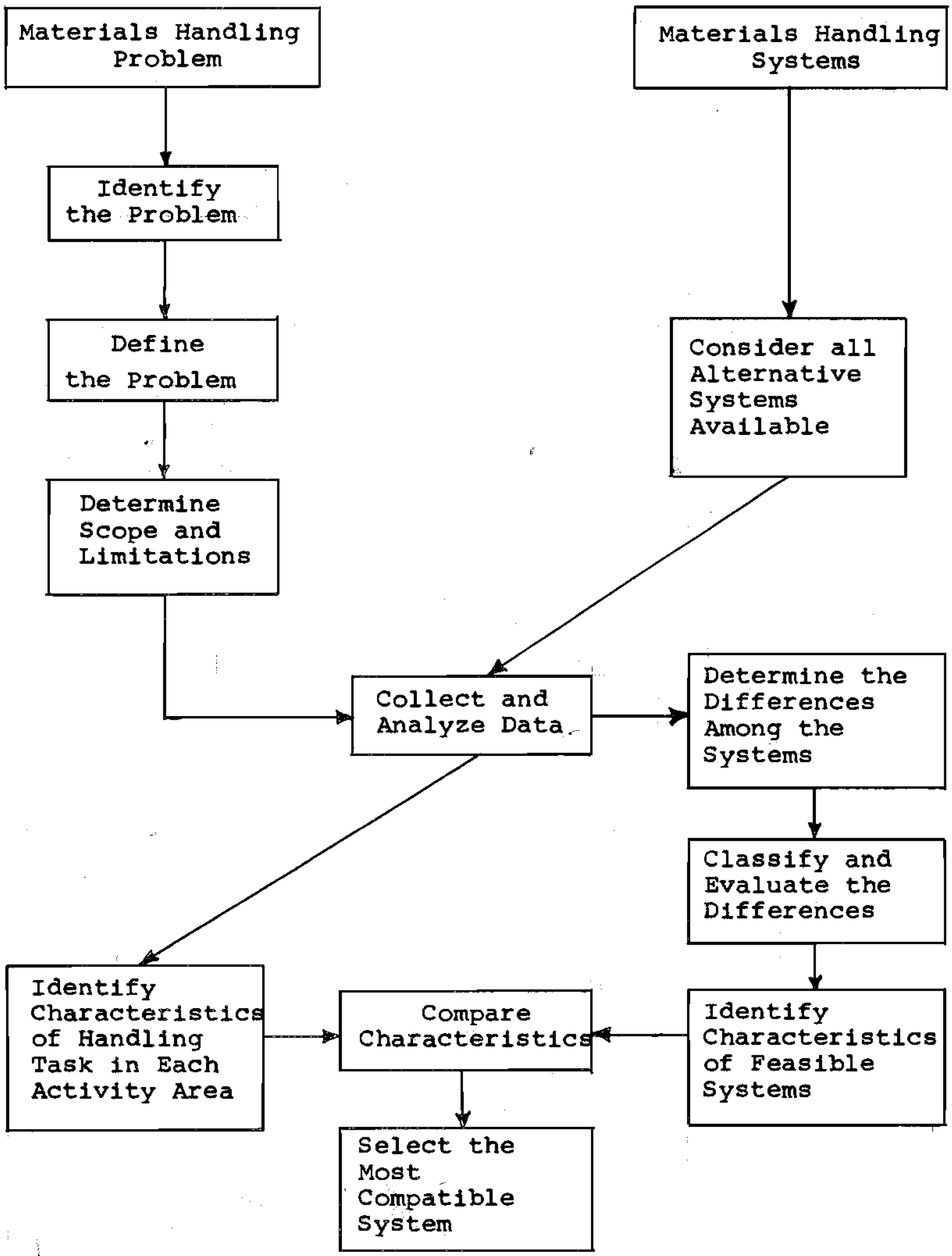


Figure 5. General Procadure for Selecting a Materials Handling System

always kept in mind when analyzing a materials handling problem. These fundamentals have been developed over a period of years and represent the work and experience of many experts in the field. They are facts which have been succesfully used and tested, while being passed on from their originators to contemporary practitioners. A set of such principles can be found in the appendix.

Aids for Selecting the Materials Handling System(s) for a Warehouse

The materials handling system is of such importance in the design of a warehouse that it is essential that a careful evaluation be made when selecting the system. The warehouse can be viewed as a facility designed to attain maximum product flow. The "smoother" the flow, the higher the efficiency of the operation, and the materials handling system provides the flow. Therefore, a set of charts has been developed here which may serve as aids in selecting the materials handling system for a warehouse. However, these charts have been developed considering the compatibility of the system with product and movement characteristics only. They do not consider two important factors which are time and cost. The complexity of relating these factors to the compatibility of the system makes it extremely difficult to determine whether optimal, or near optimal handling systems have been obtained.

Materials Handling in a Warehouse

The materials handling system in a general warehouse is usually involved in carrying out four important activities. These are:

1. Dispatching goods to storage

This activity is confined to the movement of goods from the receiving area to a required location within the warehouse. Since in distribution warehousing goods typically enter the warehouse in much larger units that those shipped from it, it can be expected that this activity will be concerned with relatively few movements of high volume shipments. Therefore, this function is one which may make use of several manual or mechanical aids. There are several factors which influence the selection of these aids. The most important ones can be classified as:

a) product characteristics, and

b) movement characteristics.

The relationships existing between these factors and the selection of a dispatching method are shown in Figure 6. On the left hand side of the figure are found product and movement characteristics. Each has been broken down into several subdivisions to aid in identifying their relationships with the several methods of carrying out the dispatching phase of the handling system of the warehouse. The top of the chart lists the general methods by which materials can be dispatched to storage.

Selection Factors \ Dispatching Methods	Manual	Conveyor	hand truck	Powered truck	Lift truck	Tow-line	Tractor Trailer Train	Overhead crane or hoist
1. Nature of Material								
a-indiv. item	x	x	x	x	x	x	x	x
b-packaged	x	x	x	x	x	x	x	
c-unit load				x	x	x	x	x
2. Shape of Item								
a-regular	x	x	x	x	x	x	x	x
b-irregular	x				x	x	x	x
3. Size of Item								
a-small	x	x	x					
b-medium			x	x	x	x	x	
c-large				x	x	x	x	x
4. Weight/Item								
a-heavy				x	x			x
b-medium		x		x	x	x	x	x
c-light	x	x	x					
5. Volume/Item								
a-small	x	x	x					
b-medium		x	x	x	x	x	x	
c-large				x	x			x
6. Turnover Rate								
a-fast		x		x	x	x	x	
b-medium		x	x	x	x	x	x	x
c-slow	x		x					x
7. Distance Traveled								
a-short	x		x	x				x
b-medium		x	x	x	x	x		x
c-long		x		x	x	x	x	
8. Path								
a-fixed		x				x	x	x
b-variable	x		x	x	x		x	
9. Frequency								
a-regular		x		x	x	x	x	
b-irregular	x		x	x	x			x
c-continuous		x				x	x	
10. Rate								
a-uniform		x		x	x	x	x	
b-variable	x		x		x			x
11. Area Covered								
a-fixed		x						x
b-variable	x		x	x	x	x	x	

Figure 6. An Aid for Selecting a Dispatching Method

Each check mark indicates that the method under which it appears, is compatible with the factor on the left hand column.

To test whether or not the chart can be used as a guide for selecting a dispatching method, two trials were made at random, selecting one possibility from each of the 11 factors. The results of these two examples are summarized in table 3. The figures under each method indicate the number of checkmarks it received during the analysis for each classification. These are then added to give the grand total.

Table 3. Summary of Test Examples for Dispatching Method

	Selection Factors \ Dispatching Methods	Manual	Conveyor	Hand truck	Powered truck	Lift truck	Tow-line	Tractor trailer train	Overhead crane or hoist
EX #1	Product Characteristics	3	5	3	3	4	3	3	1
	Movement Characteristics	1	5	0	2	1	3	4	2
	Totals	4	10	3	5	5	6	7	3
EX #2	Product Characteristics	4	4	4	2	3	2	2	3
	Movement Characteristics	2	4	1	3	2	2	2	3
	Totals	6	8	5	5	5	4	4	6

The actual choices for the two examples were:

Ex. 1) a-b-b-c-b-a-a-c-a-a-b

Ex. 2) a-b-b-a-a-c-a-c-a-b-b

The results of the first example were very specific since it showed that for the choices selected, the conveyor offered definite advantages over the closest candidates; which were the tractor-trailer-train and the tow line.

The results of the second example were a lot "tighter" than that of the first one, since no method seemed to dominate the others. However, the conveyor again came out with the highest rating with the manual and overhead crane and hoist being close seconds.

2. Storage of goods

"The function of the storage activity is to hold, protect, and preserve merchandise until it is wanted for shipment (30)." It is one of the more important activities and one of the major reasons for the existence of warehouses. There are several basic objectives which all storage areas should accomplish. These are (31):

1. Maximum use of space.
2. Effective utilization of labor and equipment.
3. Ready access to all items.
4. Efficient movement of goods.
5. Maximum protection of items.
6. Good housekeeping.

To be able to accomplish these objectives, storage areas require careful planning and analysis of the factors that influence or affect the storage activity. Figure 7 illustrates how product characteristics can influence the storage method of a warehouse.

The chart consists of a list of product characteristics, with possible subdivisions, at the left side of the chart. On top of the chart, all the available storage methods are listed. Going down the list, the checkmarks under each storage method indicate those which would be compatible with each of the characteristics. Adding the checkmarks when all the factors have been considered will reveal which storage method seems to be favored by the product characteristics. This can then serve as a guide to the selection of a general system upon which further analysis will be made to attain more specific conclusions.

Two test examples were made, by a random selection of individual possibilities for each factor, to see how these affected the storage method selected. The actual choices for the two examples were:

Ex. 1) a-b-b-c-b-a-a-b-c-a

Ex. 2) a-b-b-a-a-b-c-a-b-c

The results of these two tests are outlined in the following table.

Storage Methods / Selection Factors	PALLETS							
	Floor	Rack	Flow Rack	Conveyor	Rack	Floor	Shelf or Bin	Flow Rack
1. Nature of Material								
a-indiv. item					x	x	x	
b-packaged	x	x	x	x	x	x	x	x
c-unit load	x	x			x	x		
2. Shape of Item								
a-regular	x	x	x	x	x	x	x	x
b-irregular		x		x	x	x	x	
3. Size of Item								
a-small				x	x		x	x
b-medium	x	x	x	x	x	x	x	x
c-large	x	x			x	x		
4. Weight/Item								
a-heavy	x	x			x	x		
b-medium	x	x	x	x	x	x	x	x
c-light				x	x	x	x	x
5. Stability of Item								
a-stable	x	x	x	x	x	x	x	x
b-unstable		x		x	x	x	x	
6. Crushability of Item								
a-strong	x	x	x	x	x	x	x	x
b-medium	x	x	x	x	x	x	x	x
c-soft				x	x		x	
7. Sensitivity of Item								
a-fragile		x	x	x	x		x	x
b-perishable		x			x		x	
c-non-perishable	x	x	x	x	x	x	x	x
8. Security of Item								
a-hazardous	x	x			x	x	x	
b-secure	x	x	x	x	x	x	x	x
9. Volume/Item								
a-high	x	x			x	x		
b-medium	x	x	x	x	x	x	x	x
c-low			x	x			x	x
10. Turnover Rate								
a-fast	x	x	x	x	x	x	x	x
b-medium	x	x			x	x	x	
c-slow					x	x	x	

Figure 7. An Aid for Selecting a Storage Method

Table 4. Summary of Test Examples for Storage Method

Storage Methods / Selection Factors	PALLETS			Conveyor	Rack	Floor	Shelf or Bin	Flow Rack
	Floor	Rack	Flow Rack					
Ex. #1 Product Characteristics	4	6	5	8	8	6	10	9
Ex. #2 Product Characteristics	8	7	4	5	10	9	6	7

Both results were fairly clear, and showed tendency toward selecting "good" storage methods for the characteristics considered.

3. Order picking

This activity is charged with removing items from storage as they are called for. Since items are generally called for in relatively small quantities, this function requires more material handling per unit due to the high number of times it is performed. Therefore, it is probably the most important warehouse function. Only through a quick and efficient order picking system can a warehouse function efficiently and effectively. It is the "key" operation within the warehousing cycle, and is affected by related activities, such as dispatching and order accumulation. However, the time required to pick an order becomes critical due to the costs associated with the time lost by vehicles waiting to be serviced.

The effect that product characteristics, and movement characteristics have on the selection of an order picking method is explored in Figure 8 (see pages 48-50).

This chart operates differently from the previous ones. At the left side of the chart, product and movement characteristics, each with corresponding subdivisions, are listed. On top of the chart, all the picking methods available are also listed. At the intersection of each characteristic with each picking method, are words showing the most probable occurrence for each factor considered. By selecting a picking method, and examining all the product and movement characteristics, the conditions under which each method is most desirable can be selected. Comparing these results with certain specifications may serve as a guide to the selection of an efficient order picking system for a warehouse.

4. Order accumulation

This activity is concerned with assembling or accumulating the items which constitute a specific order as they come from the several locations in the storage area. Since orders vary in number and variety of items, and may be picked from several areas within the warehouse by different people, some method must be devised to control and coordinate the flow of material coming from the

Selection Factors \ Picking Methods	1- MANUAL METHODS					
	Walk to Order Accumulation Area	to Conveyor	to powered truck	to Tow-line	to tractor trailer train	to Hand truck
1. Nature of Material	Item	Item Packaged	Packaged Unit Load	Item Packaged	Packaged Unit Load	Item Packaged
2. Shape of Item	Irregular Regular	Irregular Regular	Irregular Regular	Regular	Regular	Regular
3. Size of Item	Small	Small	Medium	Medium	Medium	Small
4. Weight/Item	Light	Light Medium	Medium	Medium	Medium	Light
5. Volume/Item	Low	Low Medium	Medium	Medium	Medium	Low
6. Turnover Rate	Slow	Medium Fast	Medium	Medium	Medium Fast	Slow
7. Distance Traveled	Short	Medium Long	Medium	Medium Long	Medium Long	Short
8. Path	Variable	Fixed	Variable	Fixed	Variable	Variable
9. Frequency	Irregular	Regular Continuous	Regular	Regular Continuous	Regular	Irregular
10. Rate	Variable	Uniform	Variable	Uniform	Variable	Variable
11. Area Covered	Variable	Fixed	Variable	Fixed	Variable	Variable

Figure 8. An Aid for Selecting an Order Picking Method

2- LIFT TRUCK METHODS					
Picking Methods / Selection Factors	to Order Accumulation Area	to Conveyor	to Tow-line	to tractor trailer train	to pick up station for overhead crane or hoist
1. Nature of Materials	Packaged Unit Load	Item Packaged	Packaged	Packaged	Packaged Unit Load
2. Shape of Item	Irregular Regular	Regular	Regular	Regular	Irregular Regular
3. Size of Item	Medium Large	Small Medium	Medium	Medium	Medium Large
4. Weight/Item	Medium Heavy	Light	Medium	Medium	Medium Heavy
5. Volume/Item	Medium High	Low Medium	Medium	Medium	Medium High
6. Turnover Rate	Medium Fast	Fast	Medium	Medium	Slow Medium
7. Distance Traveled	Medium Long	Long	Medium	Medium	Medium Long
8. Path	Variable	Fixed	Variable	Variable	Fixed
9. Frequency	Regular Continuous	Regular Continuous	Regular	Regular	Irregular
10. Rate	Variable	Uniform	Uniform	Variable	Uniform
11. Area Covered	Variable	Fixed	Fixed	Variable	Fixed

3- OTHER METHODS				
Picking Methods / Selection Factors	Overhead crane or hoist	Stacker crane	Storage machine	Mechanical or automatic
1. Nature of Material	Item Unit Load	Packaged Unit Load	Packaged Unit Load	Packaged
2. Shape of Item	Irregular	Regular	Regular	Regular
3. Size of Item	Large	Medium Large	Medium	Medium
4. Weight/Item	Heavy	Medium	Medium	Light Medium
5. Volume/Item	Medium High	Medium	Medium	Small Medium
6. Turnover Rate	Slow	Medium	Fast	Fast
7. Distance Traveled	Short	Medium	Short	Long
8. Path	Fixed	Variable	Fixed	Fixed
9. Frequency	Irregular	Regular	Regular Continuous	Continuous
10. Rate	Uniform	Variable	Uniform	Uniform
11. Area Covered	Fixed	Variable	Fixed	Fixed

storage area to the shipping area. This is where all items for specific orders are checked and gathered together to be prepared for the final step of the warehousing cycle-shipping. It has been found that this operation can be accomplished with the aid of many manual and/or mechanical aids. The relationship existing between the more important factors influencing the order accumulation method is shown in Figure 9.

Two test trials were made to see how well the order accumulation method could be selected from product and movement characteristics. The actual choices selected were:

Ex. 1) a-b-b-c-b-a-a-b-a-a-b

Ex. 2) a-b-b-a-a-c-c-b-a-b-b

The results of these two tests are summarized in table 5. Both results seemed to be good methods of accumulating orders for the characteristics picked.

Selection Factors \ Accumulation Methods	Manual	Conveyor	Hand truck	Powered truck	Tow-line	Stacker crane	Storage machine	Overhead crane or hoist
1. Nature of Material								
a-indiv. item	x	x	x	x				x
b-packaged		x	x	x	x	x		
c-unit load				x	x	x	x	x
2. Shape of Item								
a-regular	x	x	x	x	x	x	x	x
b-irregular	x	x	x	x				x
3. Size of Item								
a-small	x	x	x					
b-medium		x	x	x	x			
c-large				x		x	x	x
4. Weight/Item								
a-heavy				x		x	x	x
b-medium		x		x	x	x	x	x
c-light	x	x	x		x	x	x	
5. Volume/Item								
a-small	x	x	x		x			
b-medium		x	x	x	x	x	x	
c-large				x	x	x	x	x
6. Turnover Rate								
a-fast		x		x	x	x	x	
b-medium		x		x		x		x
c-slow	x		x					x
7. Distance Traveled								
a-short	x		x					x
b-medium		x		x	x	x	x	
c-long		x		x	x	x	x	
8. Path								
a-fixed		x			x		x	x
b-variable	x		x	x		x		
9. Frequency								
a-regular		x		x	x	x	x	x
b-irregular	x		x	x				
c-continuous		x			x		x	x
10. Rate								
a-uniform		x			x	x	x	x
b-variable	x		x	x				
11. Area Covered								
a-fixed		x			x		x	x
b-variable	x		x	x		x		

Figure 9. An Aid for Selecting an Order Accumulation Method

Table 5. Summary of Test Examples for Order Accumulation Method

Selection Factors \ Accumulation Methods		Manual	Conveyor	Hand truck	Powered truck	Tow-line	Stacker crane	Storage machine	Overhead crane or hoist
EX #1	Product Characteristics	4	6	3	1	1	1	1	1
	Movement Characteristics	3	2	3	3	3	1	1	1
	Totals	7	8	6	4	4	2	2	2
EX #2	Product Characteristics	4	4	3	2	1	3	1	1
	Movement Characteristics	4	1	5	4	3	0	3	1
	Totals	8	5	8	6	4	3	4	2

CHAPTER V

WAREHOUSE LAYOUT

Introduction

The layout of a warehouse depends heavily upon the proposed system of materials handling; therefore, these two phases of the design must be planned together.

The interrelationship existing between the layout of an industrial facility and the material handling system is emphasized in Apple's (32) definition of plant layout:

> Plant layout may be defined as planning and integrating the paths of the component parts of a product to obtain the most effective and economical interrelationships between men; equipment; and the movement of material from receiving, through fabrication, to the shipment of the finished product.

The underlined words are a definition of materials handling, and removing them makes the definition of plant layout incomplete and meaningless. The same thing is true with the layout of almost any type of industrial facility. A layout can be considered complete only after a careful evaluation has been made of the materials handling activities involved.

General Procedure

The general procedure for developing an effective warehouse layout might proceed in the following way (33):

A. Procure and analyze basic data

1. What materials or products are to be stored in the warehouse?

2. Inventory policies.

3. Space available.

4. Funds available.

5. Manpower requirements.

6. Product(s) characteristics.

B. Determine materials handling system

1. General flow pattern types.

2. Relationship between internal and external materials flow.

3. Relationship between activities.

4. Product and movement characteristics.

5. Flow pattern.

6. Building requirements or specifications.

C. Establish space requirements

1. Storage space requirements.

2. Mayor activity space needs.

3. Service activity space needs.

D. Allocate activity areas

1. Space requirements.

2. Activity relationships.

3. Flow pattern.

4. Flexibility and expansion.

E. Coordinate planning activities

1. Flow of material thru each major activity area.

2. Relationship to master plan.

3. Service area relationships.

4. Relationship to land available.

F. Construct master layout

1. Geographical orientation.

2. Column spacing.

3. Aisle location.

4. Necessary adjustments.

5. Plot plan.

G. Evaluate layout

1. Objectives accomplished.

2. Cost of alternatives.

3. Measures of evaluating performance.

H. Install layout

1. Building design and specifications.

Developing Space Requirements

The first two steps of this general procedure (A&B) have already been completed in the previous analysis. Therefore, only a review of the necessary information is needed.

The next step in the analysis (C) is then the determination of the warehouse space requirements. A product line review, coupled with forecasts and inventory policy provide the necessary information to convert the storage requirements to basic storage units such as pallets, racks, or shelves. These can be then added to arrive at the number of basic units to be placed within the warehouse. The second step consists of obtaining the number of items to be placed in the picking area. Then the size of the reserve and bulk areas should be determined.

Finally, the amount of space needed for offices, receiving and shipping, aisles, and other service areas is determined. The summation of the areas needed to satisfying each requirement is the total space necessary for the warehouse.

An algebraic method for estimating warehouse storage space developed by Smykay, Bowersox, and Mossman (34), is presented below. This procedure is based upon the following assumptions (35):

1) The products to be stored in reserve are grouped into general categories of similar storage characteristics. Each category contains from one to n products.

2) Products placed in the selection area are assigned to special categories.

3) All products in each category may be stored at any place in the space set aside for that category.

4) The sales forecast is broken down by product line, and inventories are assigned to each product line and expressed as a definite number of pallets.

5) All products are stored on a standard pallet.

The actual quantification consists of the following steps:

1. Each storage category is represented by the letter C with suitable subscripts as follows (36):

Let C_1 designate the first category,

C_k designate the Kth category, the last category.

2. Each category contains from one to n number of products. Each product is given the letter P with suitable subscripts as follows (37):

P_{ij} where i 1, 2.....k, and j 1,2.....n.

Product $P_{1,1}$ is the first product of category one,

Product $P_{2,1}$ is the first product of category two,

Product $P_{k,n}$ is the last product of the last category.

3. The square footage of floor space is found by multiplying the length by the width of the pallet stored in the warehouse. This square footage is designated by the symbol X_{ij} where the subscripts i and j designate the categories and products as explained above. The height of the pallet stack to be stored is designated by the symbol H_{ij}.

4. Let M_{ij} be the maximum number of pallets of product P_{ij} which can be stacked upon one another. This is calculated by dividing the maximum storage height of the warehouse by the height of H_{ij}. This gives the vertical number of pallets of P_{ij}.

$$M_{ij} = \frac{\text{Maximum storage height of the warehouse}}{H_{ij}}$$

5. In a fixed time period, a given amount of inventory must be stored as indicated by the sales forecast. Let Y_{ij} be the given inventory needed for product P_{ij} during this month. However, one of the original assumptions is that all the products in a given category can be stored anywhere in the warehouse area that is set aside for that given category. Therefore, each single month must be considered for each category rather than for each product. Let the total pure or net floor space needed for category C_i be designated by the symbol F_i. The total pure or net floor space needed to store category C_i is found by the following formula (38):

$$F_i = \sum_{j=1}^{n_i} \left(\frac{X_{ij} \cdot Y_{ij}}{M_{ij}} \right)$$

The symbol N_i represents the number of products in the category C_i. However, in stacking merchandise, some space is lost between tiers, other space is taken up with pallet thickness and overhang, etc. Therefore, additional space must be added to the pure or net space required to store category C_i. The amount of this additional space is some percentage of the pure or net floor space depending upon the type of pallet and materials handling equipment used. This additional percentage is designated by the symbol A_{ij}. The formula for calculating the additional percentage is as follows (39):

$$F_i \text{ (additional percentage) } = \sum_{J=1}^{n_i} \left(\frac{Y_{ij} \cdot X_{ij}}{M_{ij}} \cdot A_{ij} \right)$$

Therefore, the total floor space needed to store category C_i including the additional percentage is (40):

$$F_i + F_i \text{ (additional percentage)} =$$

$$\sum_{J=1}^{n_i} \left(\frac{X_{ij} \cdot Y_{ij}}{M_{ij}} \right) + \sum_{J=1}^{n_i} \left(\frac{Y_{ij} \cdot X_{ij}}{M_{ij}} \cdot A_{ij} \right)$$

When these are totaled and factored, the formula becomes the following (41):

$$F_i \text{ (total) } = \sum_{J=1}^{n_i} \left(\frac{X_{ij} \cdot Y_{ij}}{M_{ij}} \right) \left(1 + A_{ij} \right)$$

This formula gives the total floor space required to store category C_i for each of the 12 months.

6. The procedure of steps three through five is repeated for all categories, and the total space for products of all categories is obtained for each of the 12 months in the budgetary period.

7. Let g be the maximum space required, F (total), for the maximum month of storage for all categories. The warehouse must be large enough to hold the maximum without running out of space.

8. Let q be the percentage of total additional space required for offices, loading and unloading, order

filling, breaking volume, consolidating, service areas, aisles, etc., all of which are necessary for efficient warehouse operation.

9. Then the total floor space needed for the entire warehouse, designated by m, is as follows (42):

$$m = \sum_{i=i}^{k} g + q \sum_{i=i}^{k} g$$

This factors into the following formula (43):

$$m = (1 + q) \sum_{i=i}^{k} g$$

which gives the total space needs for the entire building.

To illustrate how the method of calculating space requirements works, an example will be presented. Assume that a company is going to build a warehouse for storing three classes of products, which are the following:

1. Category 1 = C_1 = Paint Products
2. Category 2 = C_2 = Cooper Tubing
3. Category 3 = C_3 = Chemicals

Each category is further subdivided into two products, which are:

a. P_{11} = 1 gal. can of green paint.
b. P_{12} = 1 gal. can of turpentine.
c. P_{21} = ½" diameter, flexible copper tubing rolls.
d. P_{22} = 3/4" diameter, flexible copper tubing rolls.
e. P_{31} = 100# bags of aluminum sulfate.
f. P_{32} = 150# chlorine in pressurized containers.

A detailed description of each product with their standard load pattern follows in Figures 10-15.

For this example the values of the parameters in the model are the following:

K = no. of product categories. = 3

W = maximum storage height. = 15ft.

N = no. of products in each category. = 2

X_{ij} = area occupied by palletized product P_{ij}.

H_{ij} = height of pallet load of product P_{ij}.

Y_{ij} = amount of product P_{ij} to be stored for a given time period.

M_{ij} = maximum number of pallets per stack for product P_{ij}.

Where

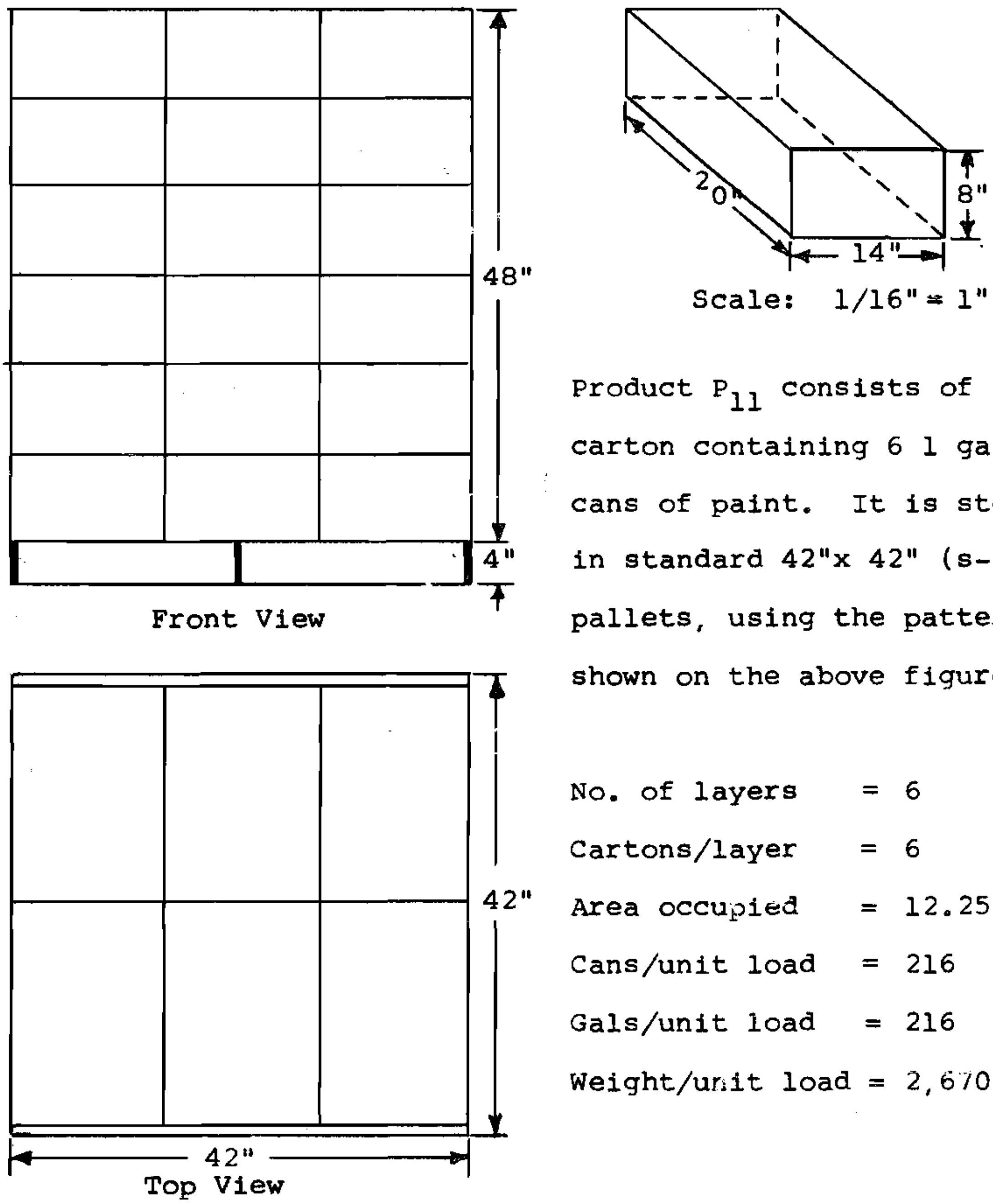
$$M_{ij} = \frac{W}{H_{ij}}$$

This gives the vertical number of pallets of P_{ij}. The maximum storage height for this example is assumed to be 15 ft. These values are summarized under each product in Table 6.

Letting the total net floor space needed for category C_i be designated by the symbol F_i, the total net space needed to store category C_i is found by the following formula:

$$F_i = \sum_{j=1}^{n} \left(\frac{X_{ij} \cdot Y_{ij}}{M_{ij}} \right)$$

The actual calculations for the space requirements are



Product P_{11} consists of a carton containing 6 1 gallon cans of paint. It is stored in standard 42"x 42" (s-2) pallets, using the pattern shown on the above figures.

No. of layers = 6

Cartons/layer = 6

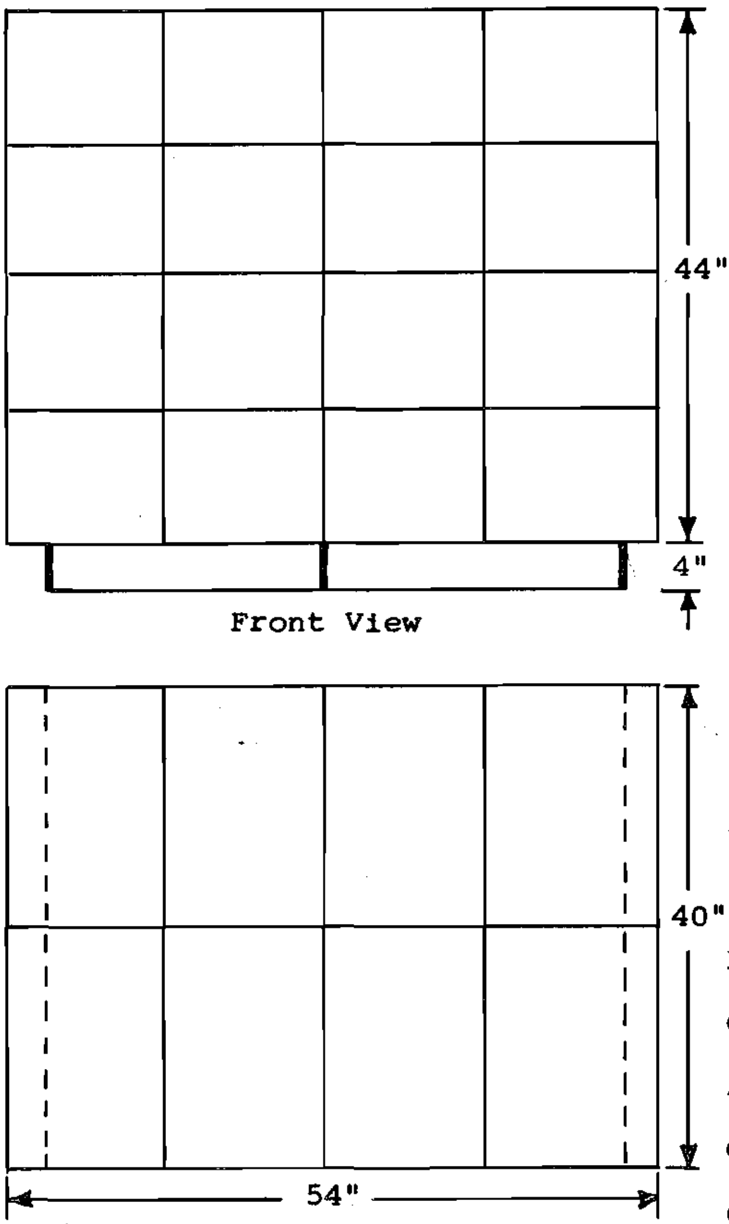
Area occupied = 12.25 ft.^{2}

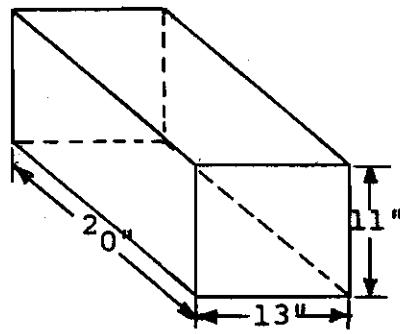
Cans/unit load = 216

Gals/unit load = 216

Weight/unit load = 2,670#

Figure 10. Product P_{11}





Scale: 1/16" = 1"

Product P_{12} consists of a carton containing 9 1 gallon cans of turpentine. It is stored in standard 40" x 48" (r-6) pallets, using the pattern shown above.

No. of layers = 4

Cartons/layer = 8

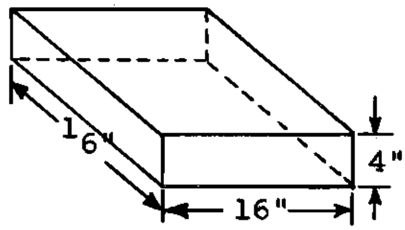
Area occupied = 13.3ft.^{2}

Cans/unit load = 288

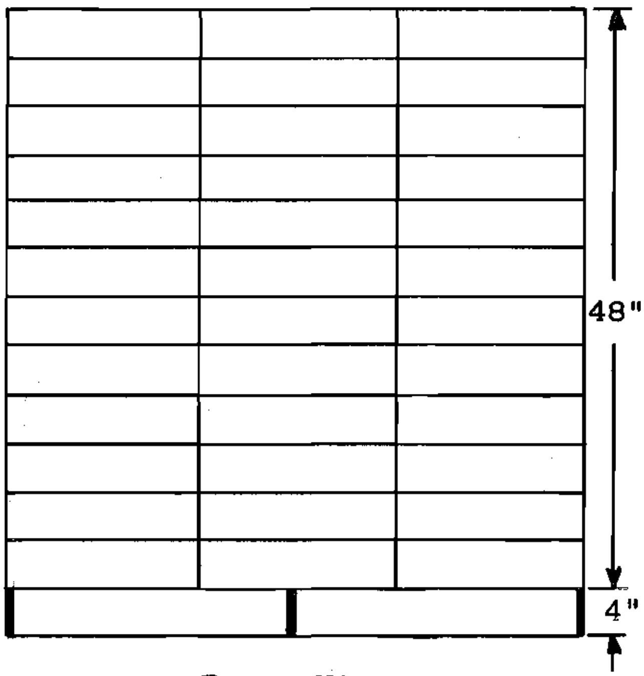
Gals./unit load = 288

Weight/unit load = 1,500#

Figure 11. Product P_{12}



Scale: 1/16" = 1"



Front View

Product P_{21} consists of a carton containing 50 ft. of flexible 1/2" copper tubing, in a roll. It is stored in standard 48"x 48" (s-3) pallets, using the pattern shown above.

No. of layers = 12

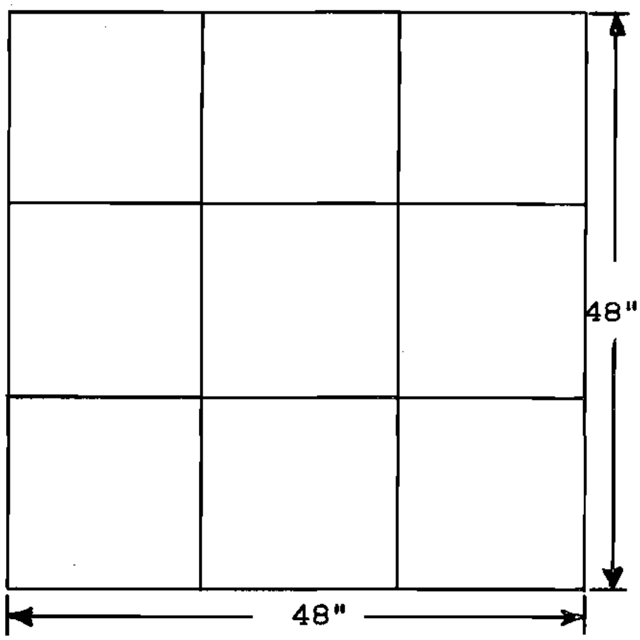
Cartons/layer = 9

Area occupied = 16 ft^2.

Rolls/unit load = 108

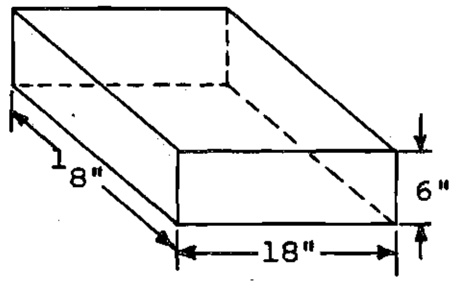
Feet/unit load = 5,400'

Weight/unit load = 1,800#

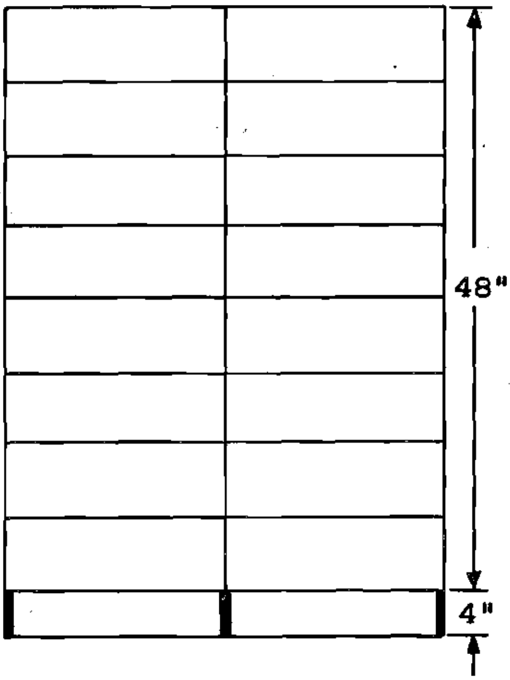


Top View

Figure 12. Product P_{21}

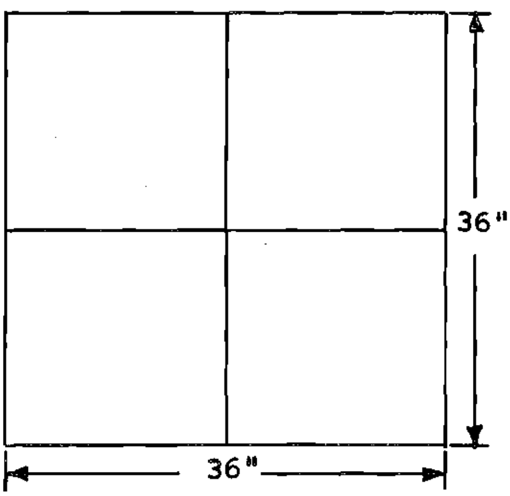


Scale: 1/16" = 1"



Front View

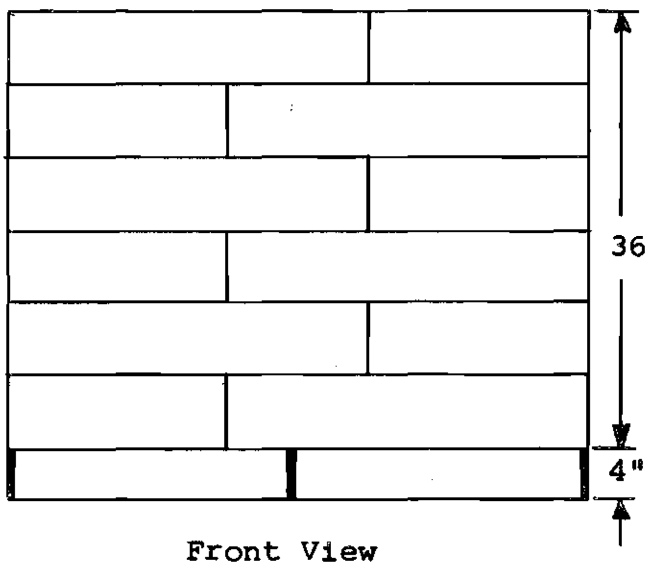
Product P_{22} consists of a carton containing 50 ft. of flexible 3/4" copper tubing, in a roll. It is stored in standard 36"x 36" (s-1) pallets, using the pattern shown above.



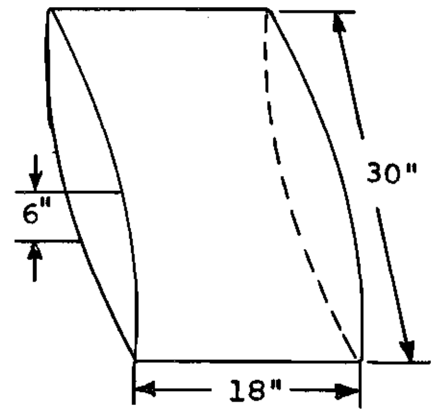
Top View

No. of layers	= 8
Cartons/layer	= 4
Area occupied	= 9 ft^2.
Rolls/unit load	= 32
Feet/unit load	= 1,600'
Weight/unit load	= 800#

Figure 13. Product P_{22}

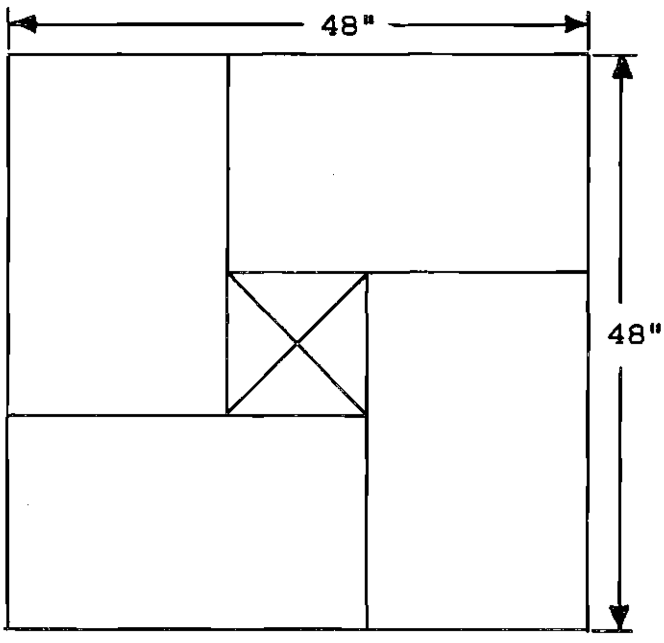


Front View



Scale: 1/16" = 1"

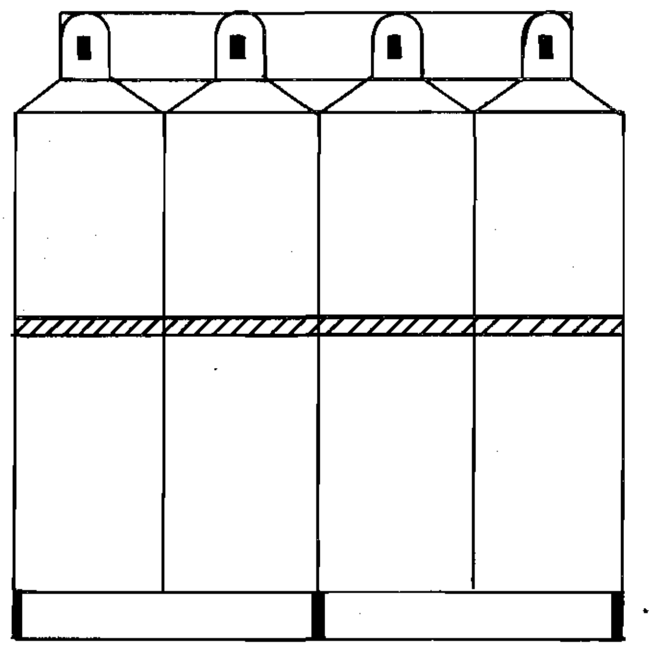
Product P_{31} consists of 100 lb. bags of Aluminum Sulfate. They are stored in standard 48" x 48" (s-3) pallets, using the pattern shown above. Pallet stacking frames are used to permit higher stacking.

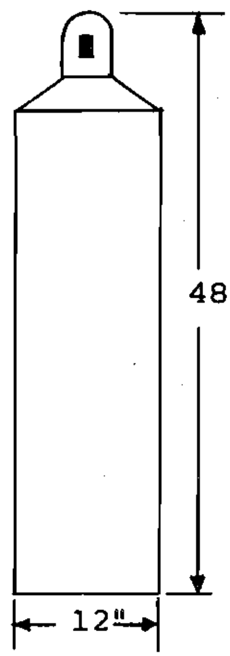


Top View

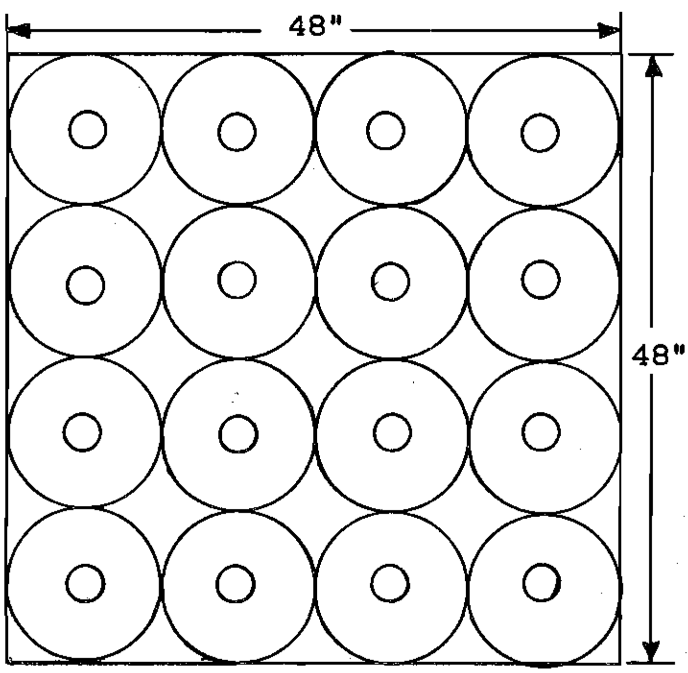
No. of layers	=	6
Bags/layer	=	4
Area occupied	=	16 ft.^{2}
Bags/unit load	=	24
Weight/unit load	=	2,400#

Figure 14. Product P_{31}





Front View



Top View

Scale: 1/16" = 1"

Product P_{32} consists of 150 lb. pressurized metal containers of Chlorine. They are stored in standard 48" x 48" (s-3) pallets, using the pattern shown above. A metal strap is used to maintain the containers together, and a metal collar protects the top portion of the containers, and permits higher stacking.

No. of layers	= 1
Containers/layer	= 16
Area occupied	= 16 $ft.^2$
Cont./unit load	= 16
Weight/unit load	= 2,400#

Figure 15. Product P_{32}

shown in table 7. The total storage space required is:

$$F(t) = F_1 + F_2 + F_3$$

$$F(t) = 554 + 369 + 437$$

$$F(t) = 1,360 \text{ ft}^2.$$

However, since some space is lost when stacking merchandise between tiers, overhang, pallet thickness, etc., some additional space must be added to the net space required to store category C_i. This is expressed as a percentage of the net floor space and is represented by the symbol A_{ij}. For this example it will be considered to be 10%. The formula for total storage space required then becomes:

$$F_i(\text{total}) = F(t)(1 + A_{ij})$$

$$F_i(\text{total}) = (1360)(1 + .10) = 1,496 \text{ ft}^2.$$

Letting g be the maximum space required F(total), and q be the percentage of total additional total space required for offices, loading and unloading, order filling, consolidating service areas, aisles, etc., the total floor space needed for the entire warehouse, designated by m, is as follows:

$$m = (1 + q) \sum_{i=1}^{k} g$$

Considering, that a warehouse utilizing 50% of its actual total space for storage of goods, is making "very good" use of the space available; the value of q for the example was assumed to be 1.2. Using this value, the total building space requirements can be calculated using the previous

Table 6. Summary of Parameter Values for Each Product

Product	P_{11}	P_{12}	P_{21}	P_{22}	P_{31}	P_{32}
X_{ij} (ft.^{2})	12.25	13.33	16	9	16	16
H_{ij} (ft.)	4.25	4.00	4.25	4.25	3.25	4.25
Y_{ij}	25,000	5,000	150,000	120,000	108,000	120,000
Unit	gallon	gallon	foot	foot	pound	pound
M_{ij}	3	3	3	3	4	3
Pallets Needed	116	18	28	75	45	50

Table 7. Storage Space Calculations

Product	(1) X_{ij}	(2) Y_{ij}	(3) M_{ij}	$\frac{(1) \times (2)}{(3)}$
P_{11}	12.25	116	3	474 ft.^{2}
P_{12}	13.33	18	3	80 ft.^{2}
F_1				554 ft.^{2}
P_{21}	16	28	3	144 ft.^{2}
P_{22}	9	75	3	225 ft.^{2}
F_2				369 ft.^{2}
P_{31}	16	45	4	180 ft.^{2}
P_{32}	16	50	3	257 ft.^{2}
F_3				457 ft.^{2}

formula:

$$m = (1 + 1.2)(1,496) = 3,291 \text{ ft}^2.$$

The formulas in ~~this model~~ show that it can be very useful in estimating space requirements. However, for a large number of categories and products the calculations are very long and tedious. A computer program would be helpful doing such calculations if practical results are to be expected.

It was also found that the total net space required, m, is very sensitive to variations in the value of parameter q. Therefore, it is of utmost importance that a careful evaluation of all the warehouse activity areas covered by the term q be done to avoid erroneous conclusions which can cause very costly errors. A more detailed analysis of those areas will follow further in the chapter.

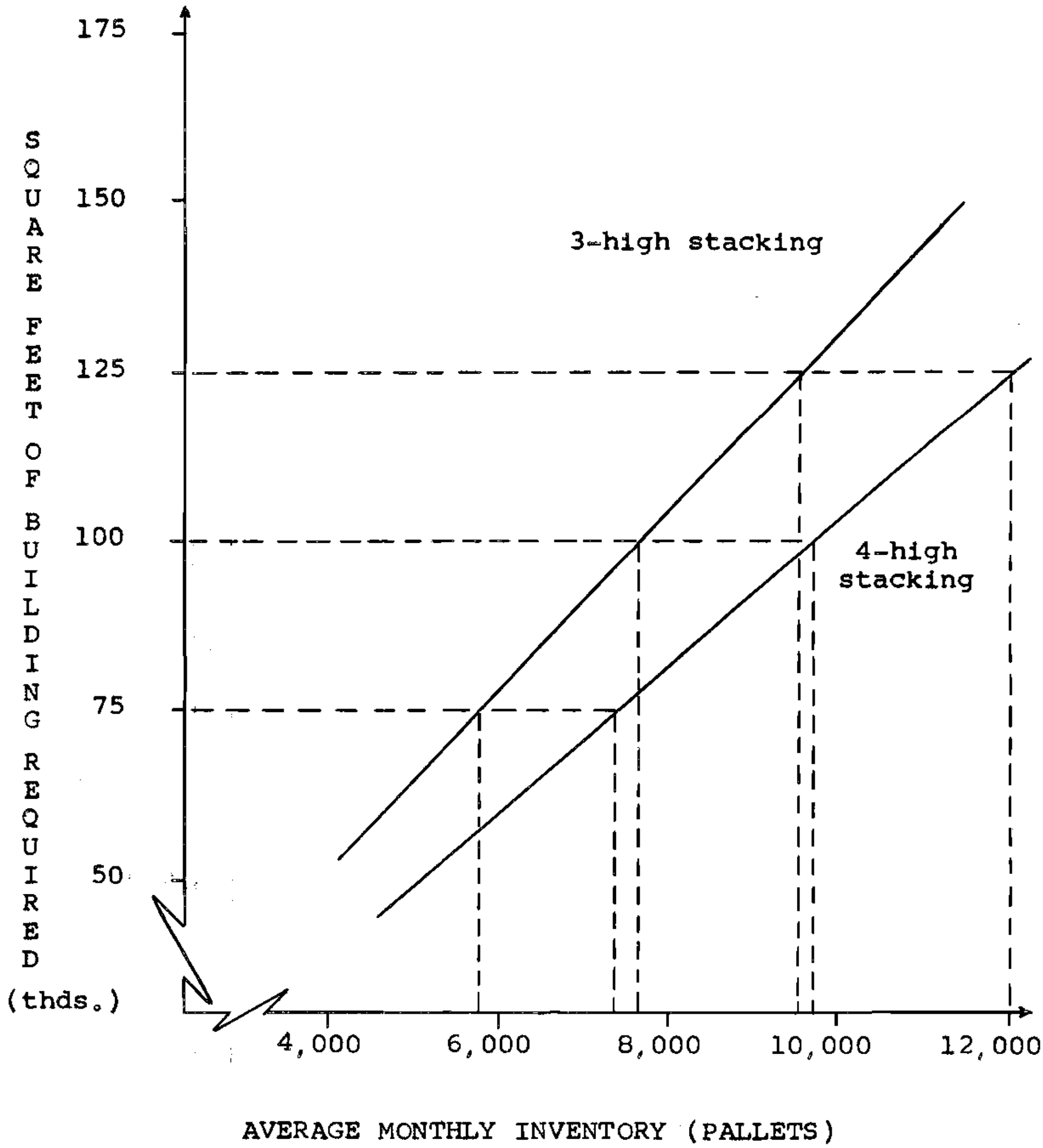
E. Ralph Sims Jr. & associates has developed a graphical model (see Figure 16) in which they relate the square feet of building required (Y) to the average monthly pallets stored (X). The equation are:

$$Y = 13.55X$$

for 3 high stacking pattern, and

$$Y = 10.15X$$

for 4 high stacking pattern.



Note:
Building space requirements are based on 85% occupancy.

Figure 16. Space Requirements Analysis

Using this method to estimate space requirements it was found that for the 267 pallets stored 3 stacks high in the example, the total space required was:

$$Y = (13.55)\ (267) = 3{,}620\ ft.^2$$

In the example, the total space for that number of pallets came out to be 2,860 $ft.^2$, which represents a difference of 26.6%.

In order to investigate why such a big difference existed between the results of both methods, the actual square footage occupied per pallet was calculated for the example presented. This came out to be 5.0 $ft.^2$ /pallet. Subtracting this from the 13.55 $ft.^2$/pallet of Sim's model, gives the area utilized by all other activities of the warehouse except storage. This is term q, as defined in the previous model. In this case, q turns out to be:

$$q = \frac{8.55}{5.0} = 1.71$$

This showed that the difference between the results was due to the different values used for q. Using a q of 1.71 for the example gives a total net space of:

$$m = (2.71)\ (1{,}298) = 3{,}520\ ft.^2$$

which is fairly close to that obtained using Sim's model.

After comparing both models, it was concluded that Smykay's model gave more realistic space requirements than

Sim's model, since a q of 1.2 gives a 45% storage space utilization, while a q of 1.71 decreases this to 37%. A warehouse utilizing only 37% of the total space available for the storage of goods is bound to be considered inefficient, while a 45% storage space utilization represents a more realistic and efficient overall warehouse performance.

Another method exists developed by Briggs (44), which can be used to determine storage space and storage aids requirements. This methods consists of a set of work sheets designed to permit easy evaluation of warehouse data. The first of these sheets is the Warehouse Planning Work Sheet, which uses three sources of data to make the evaluation (See Figure 17). The inventory and retail data is used to develop storage aid needs capable of maintaining bulk to bin replenishments to a minimum. The bulk data is used to determine information such as:

1. size and number of pallets,
2. number of racks or storage aids required, and
3. space requirements.

The instructions for filling the sheet are the following (45):

WORK SHEET INSTRUCTIONS

Enter in Col. 1, stock number of item to be considered for storage.
Enter in Col. 2, quantity on hand as shown on stock records.
Enter in Col. 3, amount due in.
Enter in Col. 4, total Col. 2 plus Col. 3.
Enter in Col. 5, total number of shipment transactions for average 90 days.

Use: This figure is used to determine relative activity of the item based on the number of times it is called for over the period.

Enter in Col. 6, total number of single units issued for average 90 days. Use:
This figure is used to determine the size bin space to be assigned to the item based on item and quantity volume.

Enter in Col. 7, size bin space to be assigned as determined from data column 6. Use: This figure is used to determine:

1. The number and size of shelf boxes required
2. The number and type of shelving required.
3. The floor space required to establish the retail issue section.

Enter in Col 8, relative activity determined as follows:

1. Fast movers, code symbol "F", those items which show the highest rate of issue frequency.
2. Medium movers, code symbol "M", those items which show the next highest rate of issue frequency.
3. Slow movers, code symbol "S", those items which show the least issue frequency.

Enter in Col. 9, size pallet to be used.
Enter in Col. 10, the number of units each pallet will hold. Use: To determine the number of pallets required.
Enter in Col. 11, Over-all height of material and pallet. Use: To determine the number of pallets that can be stacked one on top of the other within the limits of floor load and air rights.
Enter in Col. 12, number of pallets required as determined by Col. 10. Use: to requisition pallet requirements.
Enter in Col. 13, the number of pallets high, taking into consideration floor load and air rights. Use: To determine number of base pallets for computing floor space requirements.
Enter in Col. 14, all items that can be stored in one or two pallet lots using the figure 1 for a single pallet lot and the figure 2 for a two-pallet lot. Use: To determine the number of pallet racks required. The total of this column is divided by either 2 or 3 depending on height of rack used.
Enter in Col. 15, the number of base pallets required, Col. 12 divided by Col. 13. Use: To determine square feet of floor space required to store bulk stock.
Enter in Col. 16. net square feet bulk, space required, Col. 15 by 16 square feet for 40 inch x 48 inch pallets or Col. 15 by 20 square feet for 48 inch x 48 inch pallets.

INVENTORY DATA	1. Stock number	g4-b-27
	2. Quantity on hand	390
	3. Quantity due in	1,200
	4. Total quantity	1,590
RETAIL DATA	5. No. of retail issues in 90 days	120
	6. Total quantity issue 90 days	950
	7. Size bin required	#2
	8. Relative activity	F
BULK DATA	9. Size of pallet	40"x 48"
	10. Units per pallet	300
	11. Height of material on pallet	36"
	12. Number of pallets required	6
	13. Number of pallets high	3
	14. Rack space required	0
	15. Number of base pallets	2
	16. Total net square feet required	32

Figure 17. Warehouse Planning Work Sheet Data

After a work sheet for each stock class has been finished, a Warehouse Planning-Analysis Sheet must be completed for each stock group of work sheets. The analysis sheet develops in cumulative form the information required to resolve a storage problem. It consists of four main sections (See Figure 18):

1. Top section - provides physical information about building & material.
2. Section "A" - pertains to retail bin requirements calculations.
3. Section "B" - pertains to bulk requirements calculations.
4. Recapitulation section - summary of previous work to serve as ready reference.

Upon completion of this sheet a detailed description of space needs can be provided.

Service Activity Space Needs

In the model previously presented to determine warehouse space requirements, a very rough estimate of the service activity space requirements was made. However, a careful analysis of the situation is required if proper space requirements for such areas are desired. Among those auxiliary areas are:

1. aisles
2. offices
3. locker rooms and lavatories
4. general service area

A. BASIC INFORMATION
1. Stock class 2. Class description 3. Building 4. Floor 5. Load per square feet 6. Storage height 7. Column centers
B. RETAIL BIN REQUIREMENTS
1. Shelving requirements
C. BULK REQUIREMENTS
1. Rack requirements 2. Pallet requirements 3. Space requirements
D. RECAPITULATION
1. Space   4. Racks 2. Shelving   5. Pallets 3. Shelf boxes   6. Others

Figure 18. Warehouse Planning Analysis Data

1. Aisles

Space is a vital commodity within a warehouse. Therefore, it should be utilized productively. Several kinds of aisles are used within a warehouse for specific purposes. Among the more common types are (46):

a. working aisles

b. personnel aisles

c. service aisles

d. bin aisles

e. transportation

f. miscellaneous aisles

However, since space used in aisles can be considered non-productive, the ratio of aisle space to the total storage area should be kept as low as is practical.

There are many factors affecting aisle width. Among the more common are (47):

1. Handling equipment used - type, size, capacity, turning radius
2. Sizes of items stored
3. Use of the aisle - material, personnel, etc.
4. Frequency of use - volume of traffic (at peak loads)
5. Speed of travel desired
6. One-way traffic or both
7. Ease of accessibility desired
8. Lot size stored
9. Storage method used

P. T. Eaton (48), suggests the following rules, commonly used in industry, for selecting aisle widths:

<u>AISLE WIDTH USED COMMONLY IN INDUSTRY</u>

For personnel only (2 persons to pass)	30 inches minimum
For two-wheel hand truck (no passing or turning with load)	30 inches minimum
For stock truck (where other must pass around it)	20 inches plus width of truck
For stock truck (where other trucks and workers must pass	36 inches plus twice the width of trucks
For stackers hand-operated fork truck, pallet transporter, semilive skid and jack	5 to 8 feet, depending on nature of load
For narrow Aisle Industrial Trucks	5 to 6 feet depending on load
For 2,000-pound fork truck	8 to 10 feet
For 4,000-pound fork truck	10 to 12 feet
For 6,000-pound fork truck	12 to 14 feet
For Fork Trucks - angle storage	5 to 7 feet

Only after proper consideration of the many factors involved, can the type and dimensions of the aisles needed for efficient warehouse operations be determined. Then, the space requirements can be easily calculated.

2. Offices

One group of basic activities within the warehouseing cycle is that of record keeping. This is a vital element if proper control over the warehousing operations is desired. Therefore, it is important that offices in which these activities will be performed are large enough to permit efficient operations.

In general, the most important determinants of office area are:

1. the number of employees
2. the volume of work handled
3. documents required to be filed.

Office space, since it is also non-productive, should be conserved, but not at the expense of efficiency.

3. Lavatories and Locker Rooms

Some area must be designated within the warehouse to provide toilet facilities for the employees. This area can be combined with the locker room, and any other similar activity and should be located as conveniently as possible to provide easy access for all employees.

The area required for the activity depends strictly upon the type of equipment to be installed, which in turn depends upon the number of employees in the warehouse.

4. General Service Area

Some space must be provided in every warehouse for first aid or medical treatment for employees, in case an accident occurs. The space requirements for such activity will depend upon the type of service to be administered there. This will also depend upon the number of employees.

Most modern industrial facilities provide an area where employees may go to eat during their lunch or break hours. This may vary from a modern cafeteria to a group of vending machines. It must not interrupt the rest of the activities within the building and the space required for it will depend upon the number of employees.

Other Major Activity Areas

There are several other activities which must be carried on in the warehouse, but which cannot be classified as service activities. These are:

Receiving	Shipping
a. Unloading	a. Order Accumulation
b. Identification	b. Packing
c. Inspection	c. Loading
d. Sorting	
e. Dispatching	

Since the dispatching and inspection activities are closely related to the receiving function they can all be considered, together as one big activity. By the same token, order accumulation and packing are related to shipping. Since the receiving and shipping activities require similar facilities it will be considered as a joint analysis for determining which factors affect their design and the total area requirements.

1. Receiving Facilities

The receiving function at a warehouse can be subdivided into several activities. These are:

a. Unloading

b. Identification and Sorting

c. Inspecting and Testing

d. Dispatching to Storage

To have an efficient warehouse cycle it is essential that the receiving facilities be properly designed to be able to handle the incoming materials. This requires that the service docks be properly designed, and that the number of such facilities be correctly selected.

The selection of the number of service docks required for receiving operations depends on two costs:

1. costs associated with the time lost by vehicles waiting for service, and

2. costs for the construction and operation of additional service docks.

If a quantification of these costs wre possible and the probabilities of their occurence known, the problem could be solved by using the expected cost principle.

$$E(C) = C_1 \int f(x)\ dx + C_2 \int g(x)\ dx$$

Differential calculus will reveal that the optimal number of docks is given by:

$$E(C) = \frac{C_2}{C_1 + C_2}$$

This however is very seldom done because of the difficulties associated with quantification of the costs involved could easily lead to erroneous conclusions, and improperly designed docks. The solution to the problem lies in a waiting line analysis of the factors in economic conflict. This means that information such as the following must be obtained:

1. Expected number of arrivals per day
2. Average length of queue waiting for service
3. Average waiting time of an arrival
4. Average number of units in the system
5. Average time an arrival spends in the system
6. Arrival rate and its probability distribution
7. Service rate and its probability distribution
8. Percentage of time the system is idle.

These are some of the inputs which will enable a waiting line analysis to be made.

After the number of docks needed has been determined the next step is to design the docks. This is one of the most critical design features of a warehouse building since it is the bridge connecting controllable internal operations and external carrier equipment. In general, it can be said that one of the most critical dimensions in the design is the dock height. This will depend upon factors such as:

1. the floor height of the trucks,
2. the load they are carrying, and

3. certain mechanical features of the carrier such as tire size, tire pressure, and spring designs.

However, certain legal regulations and customs controlling vehicle dimensions keep variation in truck heights to a minimum among standard over-the-road carriers. This permits the problem to be solved by using dockboards, dock levelers, or other mechanical devices. However, pick-up trucks and vehicles used for local deliveries present special problems and require docks of a different height, as their floor heights are less than over-the-road carriers.

After proper consideration has been given to all the factors necessary for selecting the best unloading facilities, the next step is to see what factors determine the other activity areas.

Since the unloading of carriers and the dispatching of goods to storage generally require the handling on the same material, the "ideal" situation would call for the use of the same handling system for both activities. However, this is not always the case since there may be cases in which shipments of cartons may be palletized in the warehouse for better storage, and the opposite might occur when shipping certain products. The solution to this problem lies in expanding the scope of the handling problem to include the packing and packaging methods both the customers and the suppliers. However, even this does not guarantee that a solution to handle all cases will be obtained.

After the material has gone through the first step of the warehousing cycle-receiving-it must be identified and sorted. This function is concerned with determining what is received and where and how it should be stored. This would commonly require activities such as (49):

1. Initiation of receipt documents,
2. Maintain an Inbound Shipment Register,
3. Physically check merchandise,
4. Determine quantities received, and
5. Segregate goods received where there is any question of acceptance.

The important factors determining the size of this area are the volume of shipments received daily at the warehouse, and the quantities of such shipments. The type of material handling system used to dispatch goods to the storage area and to unload the material must also be considered since some special equipment features may require additional space for efficient operations. Finally, the time the material is going to be in the area is the last important factor that has to be given some thought.

Summarizing, it can be said that the critical factors determining the size of the Identification and Sorting area are:

1. Volume of shipments received daily at the warehouse.

2. Average quantity of material in each shipment.

3. The type of handling system used to unload carrier.

4. The time the material is going to be in the area.

5. The type of handling system used to dispatch materials to storage.

Another of the activities which belongs to the receiving area is that of inspection and testing the material. The identification of the incoming goods will tell which material needs to be inspected or tested and which does not.

The factors which determine the area occupied by these activity are mainly two:

1. the number and percentages of materials that have to be tested, or inspected, and

2. the equipment required.

Normally the quantity of material to be inspected or tested from each shipment would depend on which sampling plan is being utilized. Very seldom is 100% inspection or testing done on incoming material. Therefore, the critical factor determining the area utilized by this activity would be the equipment used.

After the material has been inspected or tested, and sorted it is then dispatched to the storage area.

2. Shipping Facilities

The shipping activity can almost be considered as the "reverse" of receiving, since both cycles resemble each other. The first step in the shipping cycle starts at the order accumulation area. This is analogous to the identification & sorting of the receiving cycle since orders of material, coming from several parts of the warehouse, have to be "pooled" together and checked to prepare them for shipping. The packing area resembles the testing area of the other cycle in that only some of the materials going to the shipping area must be packed. Finally, the loading of vehicles must be performed. Similar facilities would be required and similar handling systems are needed to load as for unloading the carriers. Therefore, summarizing it can be said that the critical factors affecting the design of the shipping cycle are as follows:

A. Order Accumulation Area

  a. Volume of orders received daily at the warehouse

  b. Quantity and variety of material on each order

  c. Order Picking system used

  d. Time material is going to be in the area

B. Packing Area

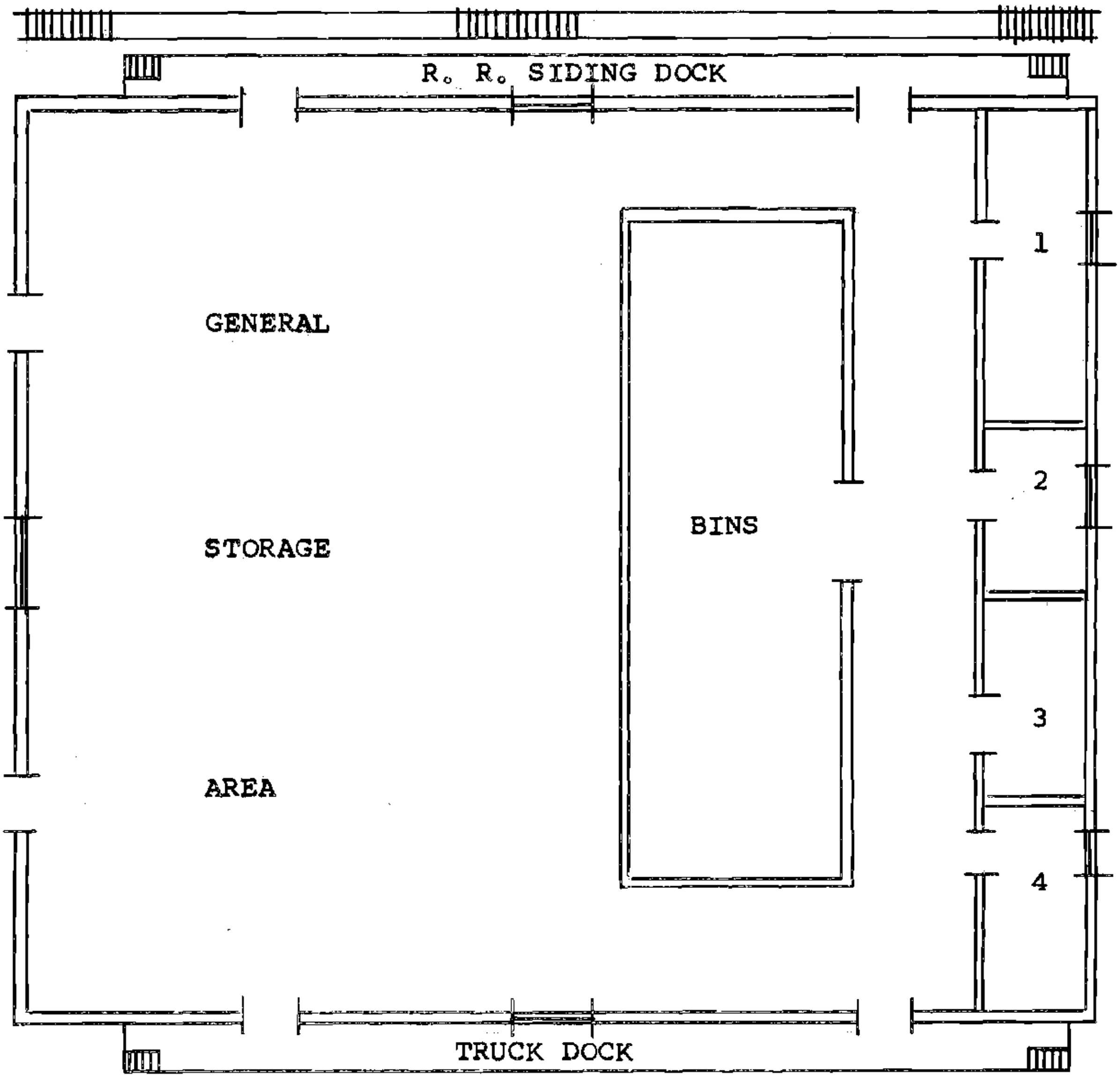
  a. The number of materials requiring packaging

  b. Packing equipment and materials used

In summary, it can be said that the total space required for efficient warehouse can be grouped in three main sections:

Total Space = Storage Area + Service Activity Areas + Mayor Activity Areas

The analysis previously presented in the chapter shows how each of these mayor components can be broken down into several groups which depend upon a number of factors and whose interrelations are somewhat complex. However, they cannot be omitted if realistic results are to be expected for the planning of an efficient warehouse.



1. infl. storage
2. office
3. security storage
4. toilet

Figure 19. Typical Warehouse Layout

CHAPTER VI

MEASURING WAREHOUSE PERFORMANCE

After all the warehouse activities have been properly grouped and coordinated, and the layout has been completed, there remains a final evaluation to see how well the overall objectives have been achieved. The evaluation of a layout may arise from either of two possibilities (50):

1. An evaluation of an existing layout for the purpose of discovering improvements.
2. An evaluation of alternative layouts under consideration for a project area.

This may be done by either qualitative or quantitative techniques.

The qualitative approach consists of listing the advantages and disadvantages of the layout(s) being considered. A more complete evaluation can be made with the use of charts as aids to help (51):

1. Spot indicators of layout problems,
2. Identify causes of the problems indicated, and
3. Find areas for possible elimination of the problems.

Quantitative evaluations might make use of one or more of the following techniques (52):

1. Rating the advantages and disadvantages
2. Evaluation of layout objectives or criteria

3. Calculation of mathematical indices

4. Cost comparisons

These are objective techniques, but extreme care must be taken when using some of them since the results by themselves can be meaningless.

The following ratios have been found to be effective means of evaluating warehouse performance:

1. Space Utilization Efficiency (SUE) (53)

This ratio shows how effectively your enclosed space is being used. The formula reads:

$$\text{SUE Ratio} = \frac{\text{Cubic feet of space usefully occupied}}{\text{Net usable cube}}$$

2. Equipment Utilization Ratio (EU) (54)

This ratio answers this question: "How much of our equipment's full capacity are we using? The aim of this ratio is to find out whether large equipment investment is paying off and, if not, how it can be made to increase return.

$$\text{EU Ratio} = \frac{\text{Actual output}}{\text{Theoretical full capacity}}$$

3. Aisle Space Index (ASI) (55)

$$\text{ASI Ratio} = \frac{r}{q}$$

where:

r = total aisle area

q = total layout floor area

This index gives a true indication of the over-all utilization of layout floor area for aisles. An increase or decrease in aisle area is readily reflected by an increase or decrease in this index value-the particular warehousing conditions encountered will determine whether a high or low is desirable.

4. Storage Volume Utilization (SVU) (56)

$$\frac{\text{SVU}}{\text{Ratio}} = \frac{V}{W}$$

where:

v = volume occupied by raw materials or finished goods at the normal maximum level of storage

w = total volume available for storage of raw materials or finished goods

This criterion shows promise of being an excellent measurement of the cubic utilization of storage or warehouse spaces such as receiving and shipping. It is also a good potential measure of proper packaging, palletizing, or materials handling, as applied to storage systems.

5. Volume-Weight Index (VWI) (57)

$$\frac{\text{VWI}}{\text{Ratio}} = \frac{M}{W}$$

where:

M = volume of material

W = weight/lb.

This ratio can be very helpful formulating the approach to storage of materials. Materials handling equipment must be selected by weight potential whenever handling material with a VWI ratio of less than 1. The VWI ratio can also be useful for "pooling" of shipments in which volume and weight characteristics of different products can be combined to reduce transportation costs.

CHAPTER VII

CONCLUSIONS

The procedure discussed in this thesis for the planning and design of a warehouse within the distribution system of a firm consists of a systematic approach to the several phases of the development of such unit. The general procedure presented here provides possible means of improving current practices commonly followed in the planning and design of warehouses. This procedure consists of five phases, as follows:

1. Economic justification of warehouse
2. Location of warehouse
3. Determination of materials handling method(s)
4. Design of warehouse layout
5. Preparation of building plans

The economic justification of the warehouse is the first step in the analysis. This consists of an economic study of the feasibility of such as link in the distribution system of a firm. Several distribution alternatives are compared on the basis of minimum cost and maximum service attained. If the results of such study reveal that a warehouse unit is economically justified, the next step is to select a location.

The general characteristics of the location problem are explored and a general procedure for the selection of a site is presented. Finally, several warehouse location models which give near optimal solutions, and which have been successfully used are presented.

After the best location for the warehouse has been selected, the problem of selecting the materials handling system for the warehouse activities is explored. The problem is subdivided and analyzed as four major activities which constitute the materials handling system of the warehouse. Several charts have been developed to serve as an aid in selecting general methods of solving the handling problem for the dispatching, storage, order picking and order accumulation activities. The method of approach is to use product and movement characteristics to select the system most compatible with the handling needs for a specific situation. It is recognized that this type of analysis will not provide an accurate relationship between the factors considered and the method used to perform each activity. However, it will serve as a guide or general method of solving the problem. Further analysis will be needed to reach a more specific conclusion.

After the handling system has been selected, the next step is to design the warehouse layout. The handling and layout functions are very closely interrelated and the efficiency of the warehouse will depend on how well they are planned and coordinated. The first step in warehouse layout consists of calculating space requirements. Two models are presented and analyzed with the use of an actual example to show how the methods compare. Then the activities within the warehouse are divided into three phases: (See Figures 20-22)

Phase I Receiving Cycle

a. Unloading material

b. Identification

c. Inspection

d. Sorting

e. Dispatching to storage

Phase II Storage Cycle

Phase III Shipping Cycle

a. Order picking

b. Order accumulation

c. Packing

d. Loading

A further analysis of the critical factors affecting the size of each area is presented for these major areas. A similar analysis is also made for several auxiliary or miscelaneous areas which are required within the warehouse. Finally, a coordination and an evaluation of the activities is made.

After this analysis is finished, the only step

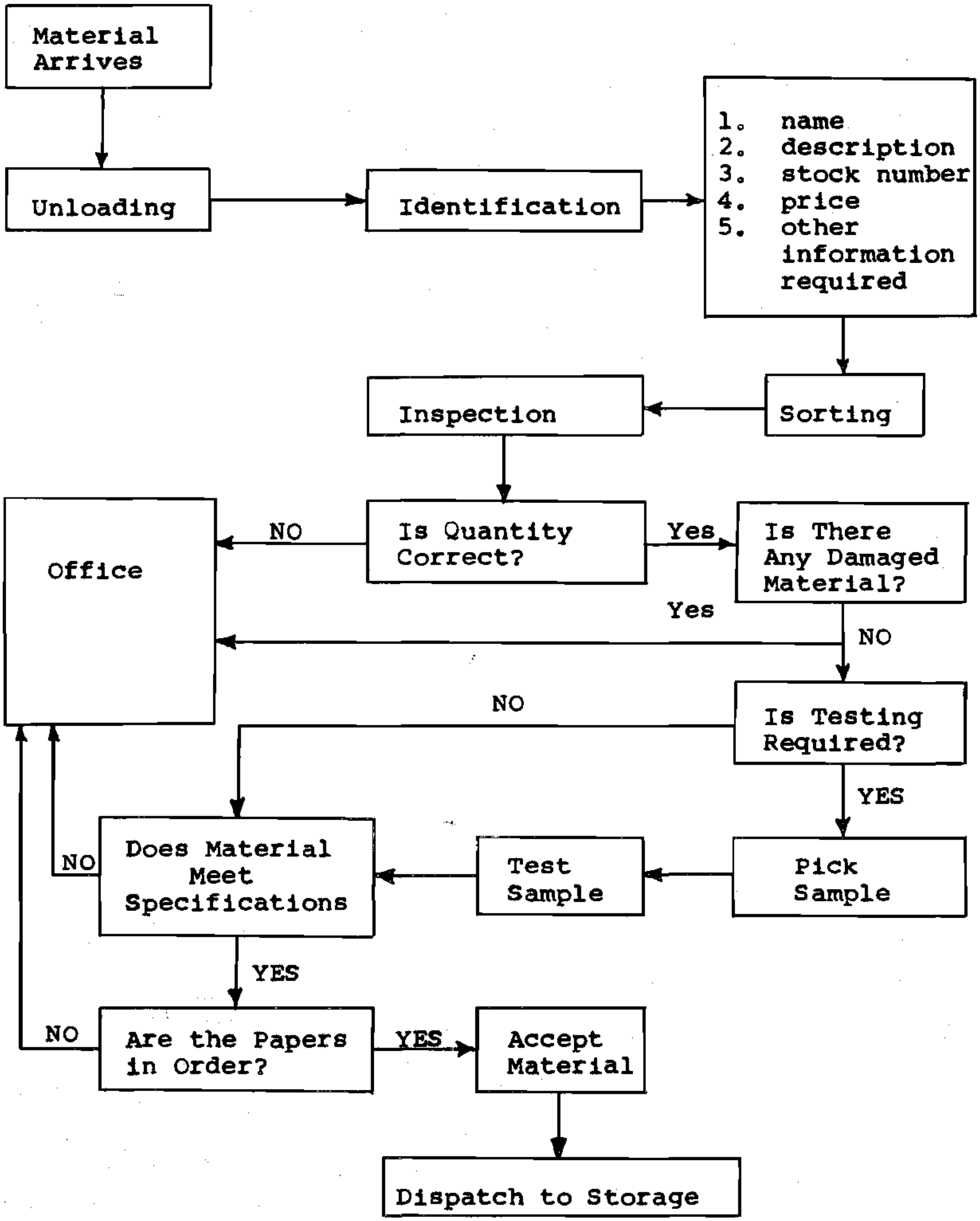


Figure 20. Receiving Cycle Flow Chart

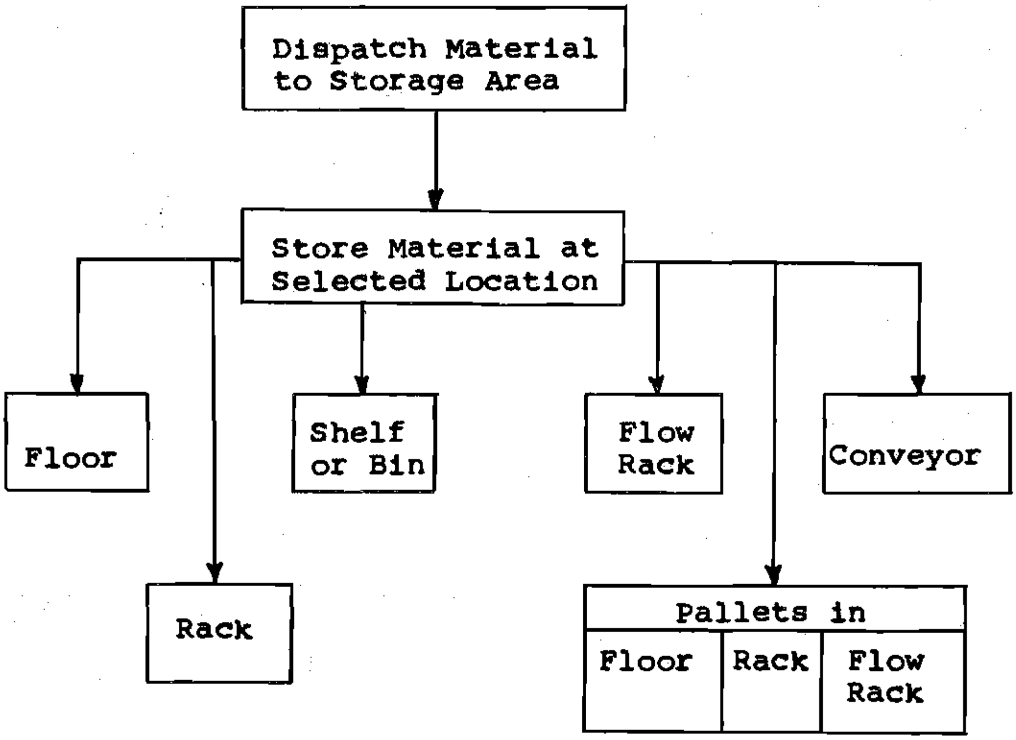


Figure 21. Storage Cycle Flow Chart

Factors Affecting Storage Method Selection:

1. Nature of Material
2. Shape of Item
3. Size of Item
4. Weight/Item
5. Stability of Item
6. Crushability of Item
7. Sensitivity of Item
8. Security of Item
9. Volume/Item
10. Turnover Rate

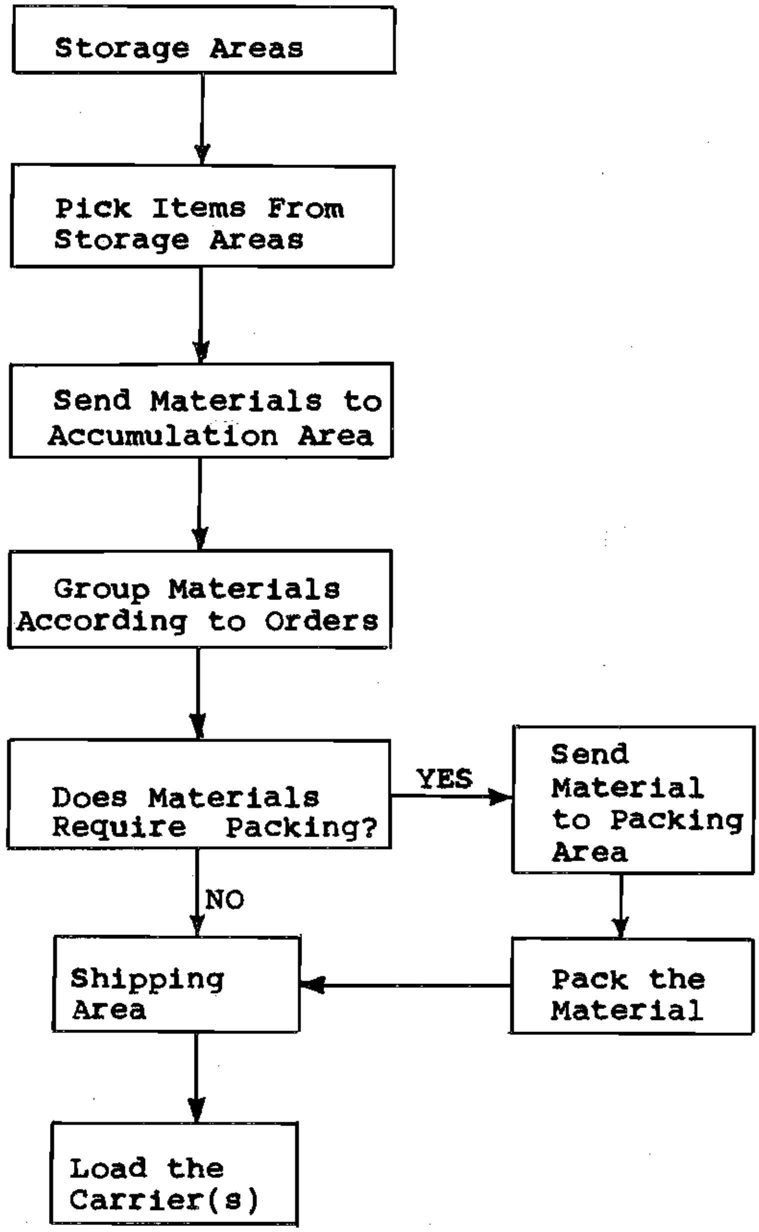


Figure 22. Shipping Cycle Flow Chart

remaining is to construct a set of plans and specifications for the construction of the warehouse.

The flow chart in figures 20-22 represents the material flow thru the warehouse from receiving, thru storage and then to shipping summarizing the warehousing activity.

This flow chart represents the approach that has been followed in this thesis. It should be emphasized that the procedure described here is a systematic way of approaching the problem, and not a formula for solving it. The procedure will aid in solving the warehouse problem, but it will not guarantee an optimum solution. In the field of warehousing, this still depends on experience.

Recomendations

An extensive literature survey conducted while collecting material for this thesis showed that there are several areas in need for further research. The following topics are presented hoping that other students use them as ideas to explore an interesting and underdeveloped field.

1. Expand on the economic justification of warehouses in the physical distribution system and construct quantitative models explaining their behavior.
2. Analyze and combine the qualitative, quantitative, and heuristic techniques available for solving the location problem into one general procedure.

3. Develop a method which considers time, cost and compatibility of the materials handling system of a warehouse with the characteristics involved.

4. Develop a procedure for using the materials handling principles as criteria in selecting handling systems.

5. Combine the methods available for calculating warehouse space requirements into precise but not too complex methods.

6. Develop criteria for setting objectives in physical distribution management and methods of measuring the achievements toward the completion of these goals.

7. Explore the relationship existing between the warehouse layout and mayor activity areas such as order picking, shipping, etc.

It is hoped that these suggestions will help to stimulate new thoughts for those following the facilities planning field.

APPENDIX

Material Handling Principles (58)

1. Planning Principle

   All handling activities should be planned.

2. Systems Principle

   Plan a system integrating as many handling activities as is practical and coordinating the full scope of operations, (receiving, storage, inspection, packing, shipping, and transportation).

3. Materials Flow Principle

   Plan an operation sequence and equipment arrangement optimizing materials flow.

4. Simplifications Principle

   Reduce or eliminate unnecessary movements and/or equipment.

5. Gravity Principle

   Utilize gravity to move material whenever practicable.

6. Space Utilization

   Make potimum utilization of building cube.

7. Unit Size Principle

   Increase quantity, size, weight of load handled.

8. Safety Principle

   ~~Provide for safe handling methods~~ and equipment.

9. Mechanization/Automation Principle

Use mechanized or automated handling equipment when practicable.

10. Equipment Selection Principle

In selecting handling equipment consider all aspects of the material to be handled, the move to be made and the method(s) to be utilized.

11. Standardization Principle

Standardize methods as well as types and sizes of handling equipment.

12. Flexibility Principle

Use methods and equipment that can perform a variety of tasks and applications.

13. Dead-Weight Principle

Reduce the ratio of equipment dead-weight to pay load.

14. Idle Time Principle

Reduce idle or unproductive time of both handling equipment and manpower.

15. Motion Principle

Equipment designed to transport materials should be kept in motion.

16. Maintenance Principle

Plan for preventive maintenance and scheduled repair of all handling equipment.

17. Obsolescence Principle

Replace obsolete handling methods and equipment when newer methods or equipment will pay off in a reasonable time.

18. Control Principle

Use materials handling equipment to improve inventory control and order handling.

19. Capacity Principle

Use handling equipment to help achieve full production capacity.

20. Performance Efficiency Principle

Determine efficiency of handling performance in terms of expense per unit handled.

LITERATURE CITED

1. Smykay, E. W., Bowersox, D. J., Mossman, F. H., "Physical Distribution Management", The Macmillan Co., 1961, p. 1.

2. Booz, Allen, & Hamilton Inc., "The Effective Management of Total Distribution Costs", Management Consultants, p. 4.

3. Apple, J. M., Bright, J. R., "Fundamentals of Material Handling", First revised edition, 1967, pps. 13-6 to 13-9, adapted from.

4. Gecovets, G. A., "Unit Loads & Containerization", Transportation & Distribution Management, March, 1965.

5. Apple, J. M., Bright, J. R., op cit, p. 14-1.

6. Keynes, J. M., "The General Theory of Employment Interest and Money", Harcourt, Brace and Co., Inc., 1936.

7. Duesenberry, J. S., "Income, Saving, and the Theory of Consumer Behavior", Harvard University Press, 1952.

8. Friedman, M., "A Theory of the Consumption Function", National Bureau of Economic Research, 1955.

9. Watts, H., "Long-run Income Expectation and Consumer Savings", Studies in Household Economic Behavior, Yale University Press, 1958.

10. Mc Rae, J. C., "The Physical Distribution System, Unpublished Term Paper for IE 613, Spring 1964, adapted from.

11. Smykay, Bowersox, Mossman, op. cit., p. 29.

12. Way, H., Smykay, E. W., "Warehouse Cost Analysis and Control", Transportation & Distribution Management, April, 1966, pps. 31-34, adapted from.

13. Hanssmann, F., "Operations Research in Production and Inventory Control", John Wiley & Sons, 1962, pps. 127-129.

14. Cooper, L., "Location-Allocation Problems", Operations Research, Vol. 11 (May-June 1963), 331-343.

15. Yassen, L. C., "Plant Location", American Research Council, 1956, revised 1960, adapted from.

16. Smukay, Bowersox, Mossman, op. cit., pps 166-169.

17. Baumol, W. J., Wolfe, P., "A Warehouse Location Problem", Operations Research, Vol. 6, (March-April 1958), 252-263, adapted from.

18. Ibid, p. 253.

19. Feldman, E., Lehrer, F. A., Ray, T. L., "Warehouse Location Under Continous Economies of Scale", Management Science, Vol. 12, (May 1966), p. 670-684, adapted from.

20. Ibid, p. 671.

21. Kuehn, A. A., Hamburger, M. J., "A Heuristic Program for Locating Warehouses", Management Science, Vol. 10, (July 1963).

22. Feldamn, Lehrer, Ray, op. cit., p. 675.

23. Fredericks, W. A, Smykay, E. W., "An Index Based Method for Evaluating Warehouse Locations", Transportation Journal, (Fall 1963).

24. Ibid.

25. Ibid.

26. Ibid.

27. Hoch, L. C., "Ten Most Common and Costly Mistakes in Warehouse Location", Transportation & Distribution Management, August, 1967, p. 25.

28. Apple, Bright, op. cit., chapters 7 and 9; Ireson, W. G., Stone, F. D., "Materials Handling in a General Warehouse", Stanford University Research Report, Nov. 1956, adapted from.

29. Hayness, D. O., "Master Chart of Basic Materials Handling Systems", Distribution Age, April, 1953.

30. Apple, Bright, op. cit., p. 14-13.

31. Ibid, pps. 14-2 to 14-4.

32. Apple, J. M., "Plant Layout and Materials Handling", The Ronald Press Co., 1950, p. 3.

33. Ibid, pps. 19-23, adapted from.

34. Smykay, Bowersox, Mossman, op. cit., pps. 250-253.

35. Ibid, p. 250.

36. Ibid, p. 251.

37. Ibid, p. 251.

38. Ibid, p. 251.

39. Ibid, p. 252.

40. Ibid, p. 252.

41. Ibid, p. 252.

42. Ibid, p. 253.

43. Ibid, p. 253.

44. Briggs, A. J., "Warehouse Operation Planning and Management", chapter 7, pps. 99-139.

45. Ibid, pps. 125-126.

46. Apple, Bright, op. cit., p. 14-34.

47. Ibid, p. 14-34.

48. Eaton, P. T., IE 424 Class Handout, Winter Quarter, 1966.

49. Apple, Bright, op. cit., p. 14-11.

50. Apple, op. cit., p. 362.

51. Ibid, p. 364.

52. Ibid, p. 370.

53. Bright, J. R., "A Management Guide to Productivity", The Yale & Towne Manufacturing Co., 1961, p. 14.

54. Ibid, p. 17.

55. Gantz and Pettit, "Plant Layout Efficiency", Modern Materials Handling, Jan., 1953, p. 67.

56. Ibid, p. 67.

57. Eaton, P. T., "Economies in Warehouse Planning Must Consider Package Space and Volume", Canadian Packaging, March, 1961, pps. 46-47.

58. Apple, Bright, op. cit., chapter 4.